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OUTLINES OF BIOLOGY

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BY

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SPECIMEN.

WITH ELEVEN PLATES AND NUMEROUS DIAGRAMS

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EDITOR'S NOTE

THE "Outlines of Biology" has been revised and supplemented so that it now completely covers the ground of the student working for the First Examination of the Conjoint Board of Surgeons and Physicians, London. In large measure it will also meet the requirements of students preparing for other examinations, such as the First Medical of London University and of Durham University.

While the limits of the subjects dealt with have been largely determined by class needs, the treatment of the matter, it is hoped, has been adequately full for the purposes of elementary scientific teaching.

Chapters II, XV, and XXII have been supplemented, while Chapters X, XI, XIV, XVI, XVII, XVIII, XXVI, XXVII, and XXVIII are new. The subject matters of Chapters XXVII and XXVIII were dealt with in past editions, but in this edition they have been entirely rewritten and amplified. Chapter XXIX has been recast and supplemented.

The illustrations have been largely added to. All the half-tone plates and the text-figures 31, 64, 65, 70, and 74 are new.

Most class books of this kind lack any formal account of Histology. In this edition an attempt has been made to present the chief elementary facts in the histology of the fundamental tissues.

The editor alone is answerable for any Mendelian interpretations which may occur in the pages of this new edition. He is also responsible for the few paragraphs here and there which in considering the relationship of the organism to the environment emphasizes the important part which the former plays. It is a strange fact, but the great majority of young students, if they have any ideas at all, start their medical studies obsessed with the conception that the environment directly determines everything, and that the organism counts for nothing. The individual organism fills their intellectual horizon to the complete exclusion of the part which the race has to play. Wherever it has seemed legitimate to correct that error, the opportunity has been utilized in these pages.

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LONDON, E

November, 1911

PREFACE

THE formal contents of this book have been determined by the syllabus of the conjoint examining board of the Royal Colleges of Physicians and Surgeons of England, issued for the guidance of candidates preparing for the examination in Elementary Biology. I have endeavoured to set forth the necessary facts plainly, but in such fashion that the relations they bear to each other, and their places in the science of Biology, shall be apparent. The actual facts can be learned only with the microscope and the scalpel. I have tried to make this book serve as a guide in the laboratory, and also to supply the necessary connecting links between the isolated facts presented by the seven or eight plants and animals selected out of the multitude of living organisms. I hope, therefore, that this book may supply outlines of Biology to those who will afterwards proceed to that special branch of Biology known as the study of medicine, and that it may also serve those who propose to devote themselves afterwards to more detailed study of zoology, with the aid of more advanced text-books.

In following so well-beaten a track, I am indebted to many predecessors, to whom I wish to make grateful acknowledgment. I have drawn all the figures specially for this book; in two or three cases directly from figures already published, in several cases from the specimens with the aid of published figures. These are acknowledged in their places; the others are original.

P. CHALMERS MITCHELL

LONDON, 1894

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OUTLINES OF BIOLOGY

CHAPTER I

PROTOPLASM

LIVING bodies possess many familiar properties which give them an unmistakable character. We may be unable to distinguish in them growth or movement, the phenomena which we associate most readily with life, but we know that we can produce, by easy mechanical or chemical methods, an arrest or alteration of the processes of life. This arrest or alteration, that we call **death,** we look confidently to be followed by gross changes in the bodily substance. The form and consistency alter: the pleasant neutrality of the odour is replaced by offensive exhalations, and the substance resolves itself into water, ashes, and gases. If we treat the living substance, be it part of a growing root, a green leaf, or part of the fresh tissue of an animal, by strong heat, by placing it in a test-tube held over a flame, first a quantity of water is driven off, and then the substance chars, and there issues a thick smoke in which ammonia and sulphur can be detected. We are thus certain of the presence of hydrogen and oxygen, nitrogen and sulphur, and the charred remains are chiefly carbon. These elements we shall find compose the chief constituents in living material.

If an exceedingly thin slice or shred of such living material be placed in water or in diluted glycerine, and examined under the microscope, it may be seen to be composed of closely packed, distinct pieces, called **cells.** If the substance chosen is a thin film picked with a needle from the surface of a leaf, or isolated pieces scraped with a blunt edge from the inside of one's own cheek, these cells in the former case exhibit definite **cell-walls** and in the latter a definite outline. In both there will be seen lying in the protoplasmic substance of the cell a central thickening or **nucleus.** The cells are therefore manifestly separate elements, and constitute what we may regard as the **structural units** of the organism. In some tissues, and especially in those of animals, the outlines of cells are not readily seen. What is more important to notice is that these cells, when taken alive from fresh tissues, and preferably from young growing tissues, are composed of a semi-transparent, colourless material, looking like thin gum into which small transparent granules have been stirred. The substance which has this appearance is **protoplasm**, and is the living part of the cells of all animals and plants. Animals and plants are alive and growing; their protoplasm is alive and growing; and we know protoplasm only as a living substance. Chemical analysis kills it, and dead material is not living protoplasm. We know that what we call protoplasm is a mixture, not a single chemical substance. It is alive, and therefore constantly building up food-materials into itself; constantly breaking down part of itself in the process of doing the work of living; constantly, again, forming substances like cell-walls, like enamel, or wax, or horn, which are derived from protoplasm, but are not protoplasm. Thus protoplasm, as we look at it under the microscope, and as we must carry it in our minds, is a flux of chemical materials, some of them food in various stages of the process of building up into living substance, some of them broken-down, waste products from the living material which has been used up,—and some of them substances manufactured by the living material. To see it one chooses young growing cells, for in older cells the living material frequently is obscured by the various substances it has made.

Protoplasm, then, is not a definite chemical compound, but a jelly-like substance one can see with the microscope when one knows where and how to look for it. However, it can be shown that protoplasm consists chiefly of the chemical compounds known as **Proteins**. The general composition of these bodies is—

Oxygen	**from**	**20·9**	**to**	**23·5**	**per cent.**
Hydrogen	,,	**6·9**	,,	**7·3**	,,
Nitrogen	,,	**15·2**	,,	**17·0**	,,
Carbon	,,	**51·5**	,,	**54·5**	,,
Sulphur	,,	**0·3**	,,	**2·0**	,,

Besides Proteins, protoplasm always contains a large bulk of **water**, small quantities of **carbo-hydrates** and **fats**, and traces of **iron** and of **phosphates** and **sulphates** of **potassium, calcium,** and **magnesium.** Hence it is probable that, if in the material called protoplasm a special chemical compound be present, the molecules of this chemical compound are much more complex than the molecules of Proteins.

Protoplasm is dissolved by weak acids or alkalies and by solutions of various salts, though in this process of solution it is destroyed, and cannot, like a simple chemical substance in solution, be recovered unaltered by precipitation or evaporation. Strong alcohol coagulates it, but this again changes it as water is withdrawn in the process. Heating it to about 40° Cent. coagulates it just as white of egg, the best-known protein, is coagulated by boiling. It must be noticed that all these methods kill animals or plants just as they alter the living material of these animals and plants. Different proteins are soluble in different solutions and coagulate at different temperatures.

But without the aid of chemistry enough may be observed about protoplasm to give it a very definite place in the world of facts. First of all, protoplasm has the power of movement. This can be seen particularly well in the delicate cells which form the hairs of many plants. The staminal filaments of *Tradescantia* (the Virginian spiderwort) are set thickly with delicate blue hairs. A newly-opened flower should be chosen, and one or two of the blue hairs must be removed with great care and placed on a slide in water under a glass coverslip. The hairs are seen under the microscope to be composed of elongated barrel-shaped cells disposed in single rows. On careful focusing, the inner wall of each cell is seen to be lined with a layer of protoplasm, thin in some regions, heaped up in others (Fig. 1, *a*). In or near the middle of the cell is seen the nucleus, a rounded, more opaque, solid-looking mass. The nucleus is embedded in another irregular mass of protoplasm, and from this to the layer round the cell-wall there pass delicate strands irregu-

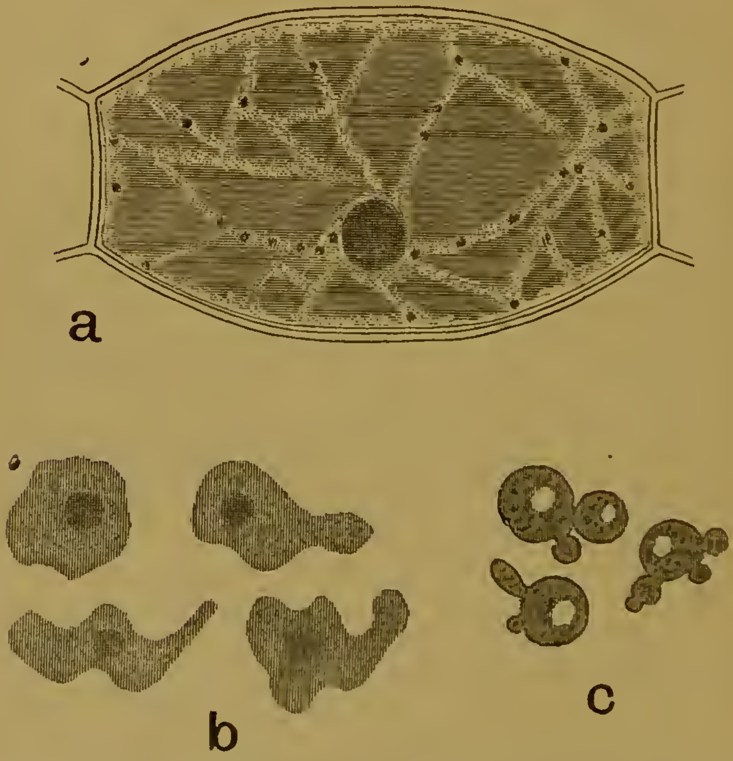


FIG. 1.—**a.** Cell from staminal filament of *Tradescantia*. The protoplasmic threads are light, and in them are contained the nucleus and chlorophyll granules. The spaces between the threads are filled by coloured cell sap.
b. A White or Amœboid Corpuscle from the blood of a frog, showing changes of shape undergone during five minutes.
c. Group of Yeast-cells exhibiting active budding.

larly arranged and often branching and running into each other. In this network of protoplasm may be seen granules of different shapes and sizes; some are opaque, some readily catch the light if one moves the mirror of the microscope backwards and forwards. When the eye has become accustomed to the semi-transparent protoplasm, it may be seen that constant streaming movements take place, especially in the fine strands running to and from the nucleus. In some of these, the protoplasm and granules are moving towards the nucleus, in others, away from it; while occasionally in the same strand there are two currents passing in opposite directions. In this restless activity the shape and direction of the strands are always changing, some disappear, new ones arise, the cross connections break down and are reformed in new places, and the whole appearance of the network changes from time to time. **Living protoplasm moves**, and this movement is the manifestation of a molecular unrest, producing a condition which we may term **irritability.**

Another kind of movement can be seen in white blood-corpuscles. If a drop of fresh blood, taken from a newt or frog, be placed on a perfectly clean slide and covered by a thin cover-slip, the microscope reveals the presence in it of a number of large oval cells with regular outline and reddish tinge (Pl. IV 2). But among these may be seen a less number of smaller, irregularly shaped, transparent masses of protoplasm. As the preparation would soon dry by evaporation if unprotected, a film of oil should be drawn with a brush round the edge of the cover-slip. Then, if we watch one of these white or colourless corpuscles, we see that the shape slowly changes (Fig. 1, *b*). At first, most probably, it appears covered with delicate prickles, which are really extensions of the protoplasm of the cell. Sometimes some of these processes lengthen, become thicker, and even may bend on themselves. A group of processes may get pushed out on one side, while those on the other become withdrawn. Moreover the shape of the whole cell is constantly altering, and the cell itself slowly creeps or moves through the liquid in which it is floating, by the extension of processes on one side and their retraction on the other. Careful focusing shows that, as in the hair-cell of *Tradescantia*, the protoplasm appears to consist of a clearer substance with granules embedded in it, and both clear substance and the granules share in the streaming movements. In this case, however, the movements, instead of being confined within a motionless cell wall, cause movement of the whole cell from one point to another. This second kind of movement is called **amœboid,** and the processes which are pushed out and withdrawn are named **pseudopodia.** With other forms of protoplasmic movement the student will become familiar, but these two forms may be taken as sufficient to show the fact of movement.

The movements of the protoplasm of *Tradescantia*, or of the white corpuscles, sometimes cannot be seen when the preparation has just been made, whereas after a few minutes they are very visible. The shock of removal to the glass may have arrested their motion, and slight pressure with the point of a needle on the surface of the cover-slip may again produce quiescence, while activity is resumed if the stimulus has been slight enough to do no damage. Gentle warmth stimulates the movements until about 45° Cent. has been reached, when all movement ceases. Electric shocks, and the application of many chemical substances, accelerate the movements. All these show the second striking fact about protoplasm—that it is **irritable,** that is, able to respond to stimuli. Besides the stimuli mentioned, a very little observation of the protoplasm in living animals and plants shows that light, food, variations in the fluids, purity or impurity of the fluids in which the organisms are living, serve as stimuli, increasing or diminishing protoplasmic activity. This power of response of protoplasm, however, depends not only upon the presence of external stimuli, but also upon the inherent molecular structure of the protoplasm itself. Without that structure the external agents would be powerless to call forth responses.

Next, protoplasm **absorbs food.** Sometimes, as with animals, the food consists of the bodies of other animals and of plants: sometimes, as in most green plants, the food is purely inorganic. The details of the nutrition of protoplasm will have to be considered later on. Protoplasm constantly is exchanging gases with the surrounding air or water ; but the details of the **respiration** or breathing of protoplasm must also be treated at length later. As a result of feeding, protoplasm **grows.** Sometimes, as in the body of an adult, growth is only sufficient to keep pace with the waste of tissue which goes on in all living animals and plants. But in the greatest number of cases growth means actual increase in size. The separate cells, however, do not grow indefinitely large. In growing tissues or in unicellular organisms, after a certain size, which is different in different kinds of cells, a cell on the point of overgrowth gives off a bud which becomes another cell, or which directly divides into two daughter cells. If we examine with the microscope some of the white frothy substance from a brewer's vat called yeast, we see that most of the separate round cells which have been floating in the sweet nutritious juices in the vat are actively budding (Fig. 1, *c*). This is the simplest kind of **reproduction,** and in reality is a form of growth.

Finally, protoplasm **excretes,** or turns out waste products. In the processes of life, substances generally coming from broken down protoplasm are extruded by the protoplasm. Many of these substances are soluble in water, and are turned out in a watery fluid. The actual occurrence of this can be seen beautifully in many single-celled animals. If one takes some pond or ditch water and examines it under a microscope, many small animals and plants may be seen. But if it be poured overnight into a flat pan in which two or three clean glass slides have been placed, a number of single-celled organisms will settle down on the slides during the night. If these slides be lifted out carefully, wiped on the under surface and covered with a cover-slip, one can hardly miss finding a minute single-celled animal, from the spherical wall of which there radiate out a number of slender knobbed pseudopodia. The protoplasm is clear and granular; there is a small nucleus; but most obvious is a round spot that looks empty, and that has a diameter at

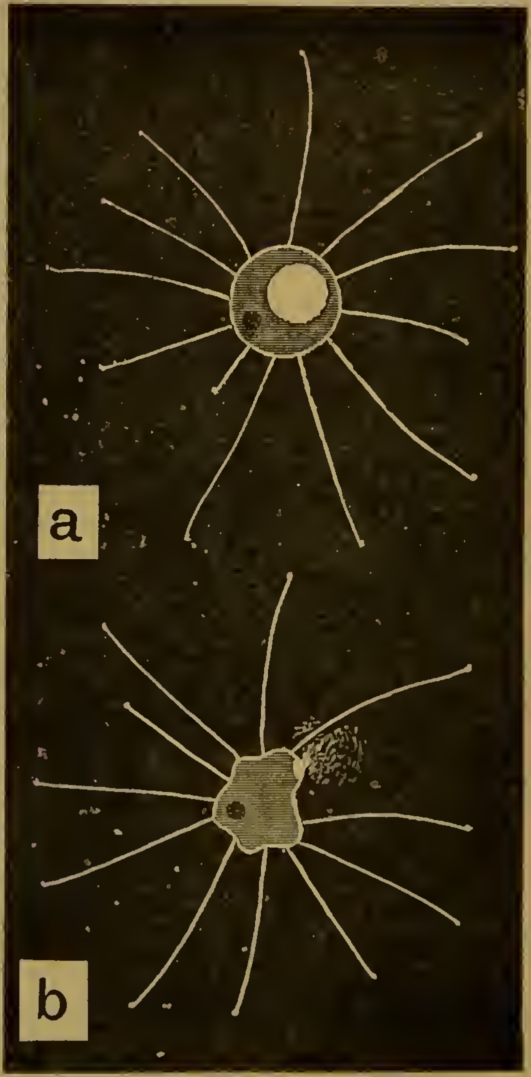
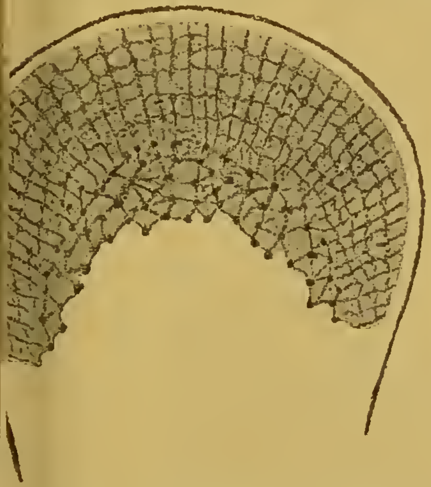


FIG. 2.—**a.** A Single-celled Animal (belonging to the *Acinetaria* or suctorial *Protozoa*) with delicate spherical cell-wall, and long knobbed pseudopodia; within the protoplasm lies a small nucleus and a large contractile vacuole.
b. The same; the contractile vacuole has disappeared, the contents being extruded: the shrivelling of the cell-wall shows the loss of bulk undergone.

least half the diameter of the whole animal (Fig. 2, *a*). As one looks at it, it suddenly disappears; the round disc of the cell becomes shrivelled, and in the water a little whirlpool is seen, as if an oily liquid had been squeezed out (Fig. 2, *b*). Slowly the spot reappears, gets larger and larger, and bursts again, and in a few minutes it may be seen to fill and empty several times. This spot is called a **contractile** or **pulsating vacuole**, and a contractile vacuole is the most visible form of protoplasmic excretion. In most cells the process of excretion goes on slowly throughout the cell, and no special vacuole is seen. But it may be taken for granted that excretion, whether visible or not, goes on in all protoplasm. One must not confound it with the extrusion of solid indigestible particles—a process which can be seen in some living cells—especially animal cells.



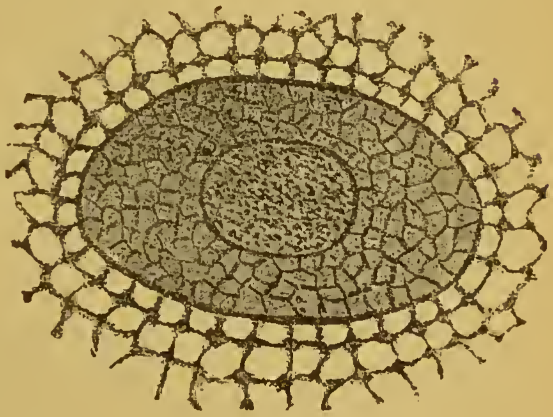


Fig. 3.—Protoplasm of *Amœba actinophora*.

Fig. 4.—Protoplasm of nucleus with part of surrounding protoplasm from ganglion cell of an ox. (From Bütschli.)

Protoplasm, then, is the living, semi-transparent, jelly-like substance composing the bulk of the living cells of animals and plants. It is made up chiefly of water and of the chemical substances known as proteins, and it possesses the properties of—**Movement, Irritability, Feeding, Respiration, Growth, Reproduction**, and **Excretion.**

Under high magnification it may be seen that many of the granules appear like the crossing points of a fine mesh-work, and that protoplasm apparently consists of a firmer mesh-work, the strands of which are refractive, and a more fluid substance which fills the interstices of the mesh-work (Figs. 3 and 4). Professor Bütschli has shown recently that an artificially produced very fine froth or foam exhibits under the microscope precisely the same appearance (Fig. 5). In his artificial foams the minute bubbles consisted of tiny drops of a kind of soap in solution, each surrounded by a thin film of oil. When a drop of this foam is brought in contact with water, streaming movements, closely resembling the movements in protoplasm, are produced, and the drop of foam moves slowly through the water. It is therefore quite possible that the network of protoplasm really is a fine froth, the strands being a fluid surrounding droplets of another fluid—the apparently more liquid part of protoplasm.

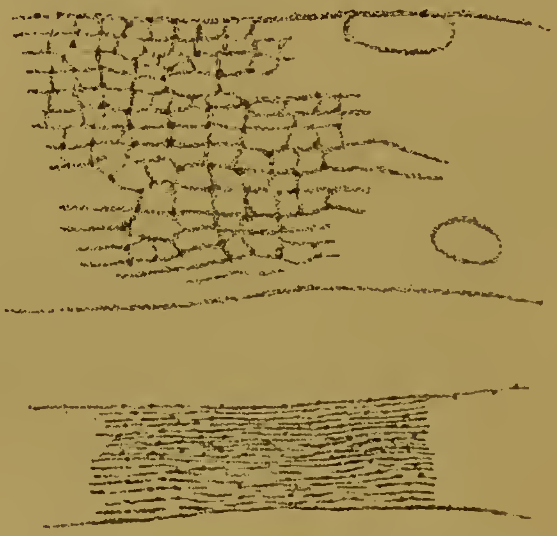


Fig. 5.—Foam of Olive Oil and Carbonate of Potassium, very viscous, much magnified and pressed into fibrils by the cover-slip. The upper figure is a higher magnification of part of the lower figure. (From Bütschli.)

There are several theories as to the physical constitution of protoplasm, but it would serve no useful purpose to further consider them here,

CHAPTER II

THE BUILDING UP OF PROTOPLASM

PROTOPLASM and substances formed by it are the material of the tissues of all animals and plants; and all animals and plants, in consequence of this, have the powers of **Movement, Irritability, Assimilation, Respiration, Growth** and **Reproduction,** and **Excretion.** The individual cells of the animal or plant bodies may be built up into complicated tissues and organs which serve special purposes, and in the elaborate systems of higher animals and plants these tissues and organs may assist, or regulate, or interfere with each other's work. But, in every case, the actual work done is done by individual cells, and the result that we see is the combined work of the large number of individual cells present in the organs. For instance, the hands may take food to the mouth, the teeth chew it, the muscles of the tongue and mouth and gullet force it down; but it is ultimately the individual cells lining the intestines that absorb and really assimilate the meal. Similarly all the powers of animals or plants can be traced down to individual cells, down to protoplasm itself.

Practically, then, the living world is protoplasm. In the processes of life, protoplasm is constantly being used up. A starved organism loses in weight, and even while food is abundant, protoplasm is constantly undergoing change and being broken down. When an animal or plant dies and decays, protoplasm is destroyed. How, then, is this substance built up from the inorganic materials in the world?

If we consider the food supply of the land, it is clear that flesh-eating animals practically only turn the protoplasm of their prey into their own protoplasm, and that their life is dependent on the life of other animals. Animals with an omnivorous diet live partly on animal protoplasm, partly on the tissues of plants. Other animals live entirely on plants. If, seeking an answer to our problem, we turn to plants, we can dismiss many which, like moulds and fungi, live on living or decaying organic matter, and we are left with the green vegetation of the earth. The food supply of the sea is less easy to understand. The vast majority of marine animals are predatory. Most seabirds are fish-eaters; most fish live on other fish, or on small swimming animals like the larvæ of crustacea which abound in the waters. Others live on the shellfish of the bottom, or on worms and anemones and coral polyps. Most of these lower forms of life are themselves carnivorous, and at first sight it seems as if there was no answer to our problem. The amount of floating seaweed or the seaweed round the coasts is not nearly enough to replace the vegetation of the land. Some *débris* comes down from the land; the sewage in the Thames, for instance, ultimately supplies food for the rich fishing stations off Yarmouth or on the Dogger Bank; the sewage of the Clyde fattens the herrings of Loch Fyne. But the greater part of the open sea is not supplied with organic remains from the land. If, however, we examine a bucket of surface water, there are to be found in it innumerable microscopic plants, and these, like the green vegetation of the earth, form the first stage in the building up of protoplasm; and, like most plants with which we are familiar, very many of these minute plants have a green colour. The starting-point of the food supply of land and sea is green vegetation. The formation of protoplasm from inorganic materials depends on the substance to which this green colouring is due, and which is called **Chlorophyll** (green of leaf). If some green leaves are soaked in alcohol, the green colouring matter is dissolved and forms a clear solution, bright green in colour. This solution is *fluorescent*, for it is green when the light shines through it, but the colour appears red under a strong reflected light.

When examined under the spectroscope its spectrum is seen to give strong absorption bands in the red and orange end, but only a faint and diffuse absorption in the blue and violet. There probably is a connexion between this large absorption of thermal energy and the striking functions of chlorophyll. Every living cell containing chlorophyll in the presence of sunlight performs chemical work. It absorbs carbonic acid from the air, partly dissociates the carbon and oxygen, returning the liberated oxygen to the air. The carbon is not retained as pure carbon, but, probably in the act of being separated from the carbonic acid, is associated with hydrogen and oxygen in the form of a simple carbohydrate—that is, a compound of carbon, hydrogen, and oxygen, in which the hydrogen and oxygen are in the same proportion as they are in water.

This leads to another striking fact. Carbon combines readily with oxygen, and in the process sets free energy in the form of heat. What then takes place in plants, by the agency of chlorophyll, is a turning of radiant energy of sunlight into potential energy; the radiant energy is stored up in the form of a chemical compound of such a kind that, by union with free oxygen, it will liberate the energy again.

From one point of view plants and animals, or the protoplasm of which they consist, may be regarded as centres of force, as things capable of doing work; and here, as the secret of their food-supply, as the first stage in the building up of protoplasm, is to be found a supply of energy, a means by which the radiant energy of sunlight is stored up in a form which can be used. The plants which possess chlorophyll store up the energy: the animals which feed upon plants use this store for their own lives, but retain enough in their own bodies to serve for the carnivorous animals which eat them. Carbon or Carbohydrates, when supplied with oxygen, form carbonic acid, and give out energy as heat. Although the chemical details of the processes of life—what is called the **metabolism** of protoplasm—are very complicated, it may be said generally that protoplasm takes in oxygen, performs the work of life, and gives out carbonic acid; and that it is enabled to do this by the capacity chlorophyll has for absorbing the energy of sunlight and storing it up in the form of carbon compounds with less oxygen than the proportion in carbonic acid (CO_2).

Speaking generally, dead protoplasm, at the moment of its death, has approximately the same composition as living protoplasm. But yet dead and living protoplasm are very different things. Dead protoplasm was once living protoplasm, and but a moment before was protoplasm in the full play of the energies of life. Yet it is incapable of doing what living protoplasm can. Left to itself it gradually undergoes dissociative changes, it becomes less and less in bulk and ultimately disappears, all except a mere trace of mineral dust. But it is not destroyed. For in the course of its disintegration it evolved heat, carbonic dioxide gas, water, and some ammoniacal or other nitrogenous body in one form or another. There has been a transformation but not destruction. There is no such thing as destruction in the literal sense. The living world, like the universe, is a seat of constant change, not of creation or destruction. Nothing is new, nothing is lost, all is change and recombination of old materials and existent forces. Out of inorganic matter protoplasm is built up, into inorganic matter it becomes dissociated as the normal function of its living activities, and to inorganic matter it returns as the transient destiny which follows its death.

Living protoplasm, like dead protoplasm, is continually giving off heat, carbonic acid gas, water, and some nitrogenous compound, but unlike dead protoplasm it does not disintegrate and disappear. It maintains itself by replenishing its lost matter from the food taken in. But food may be very different in its chemical and physical properties to that protoplasm into which it is to become incorporated, and which transiently it will become. Clearly, then, between the taking in of crude food substances at one end, the building up of these into living protoplasm, and the discharge of waste substances at the other end of the cycle of vital activities, some profound changes must occur. The food must undergo a series of modifications, at each stage of which it becomes more like protoplasm, less like food, until at last it is living protoplasm itself. This building-up process of the food into living protoplasm we may speak of as **anabolism** or **assimilation,** and the different bodies formed in the successive stages as **anastates.** No sooner are these anastates incorporated into living protoplasm, than they unite with oxygen, a process which constitutes the fundamental act of **respiration.** Thence the protoplasm breaks down into more and more highly oxidized bodies or **katastates,** and at each stage in this down-breaking process the products of oxidation become successively less like the protoplasm from which they are derived and resemble more the ultimate waste products to which they will give rise. This series of changes constitutes **katabolism.** And the whole cycle of changes comprised under anabolism and katabolism may be termed **metabolism.**

CHAPTER III

SINGLE-CELLED ORGANISMS

Protophyta and Protozoa

THE complexity of structure which we see in higher forms of life, in Man and the rabbit, the oak-tree and the geranium, may be necessary for the higher or more complicated life which such forms live, but it is not at all necessary for the manifestation of life itself. For the particular attributes which are collectively the indications of life, which supply the only answer that we have to the query, What is life ?, are exhibited by the simplest forms of living things. So simple are these organisms that in many cases they are merely a microscopic speck of protoplasm without cell-wall or organized nucleus. In other cases they have a nucleus and no cell - wall as in the Proteus animalcule (*Amœba*), or a cell-wall and no organized nucleus as in bacteria. In others a cell-wall and nucleus are present, as in the slipper animalculæ (*Paramœcium*), and in lowly green plants, such as *Protococcus*, or non-green plants or fungi, like the yeast plant.

All these simple forms of microscopic life are unicellular organisms, that is, individuals which never become more than a single cell. They end life as they began it in so far that their organization never becomes, as in higher forms, a mass of cells, but permanently remains a single cell. Yet small in size, simple in structure though these forms are, they are capable of manifesting all the phenomena of life which the higher forms exhibit. They **ingest** food material, **digest** it, and **assimilate** it ; they **respire, secrete** various ferments for the purposes of digestion and assimilation, **excrete** waste products, and manifest **irritable responses,** in one form or another, to changing environmental conditions ; they also maintain themselves in time and space by multiplication of their numbers ; or, in other words, they exhibit the phenomenon of **reproduction.**

The manifestations of life as they are exhibited in higher forms are, of course, of a more complex kind, but essentially life is the same throughout the animal and plant kingdom. The complications and interdependency of the various functions and structures of living organisms in higher forms render the study of life in them very difficult. It can be much easier studied in the simplest forms. For here we see it in its simplest and most isolated manifestation. We shall therefore proceed next to study some unicellular plants and animals.

CHAPTER IV

UNICELLULAR PLANTS (PROTOPHYTA)

NON-GREEN PLANTS (FUNGI)

The Yeast Plant (*Saccharomyces cerevisiæ*)

ONE of the simplest of unicellular plants is the yeast fungus (*Saccharomyces cerevisiæ*). The pale yellow, frothy substance known as brewer's yeast, which rises as a scum on the surface of fermenting vats, and which is used by bakers to make dough "rise," consists of a fluid in which are suspended immense numbers of minute particles just visible with a low power. Each of these particles is a single-celled organism—the yeast plant. Each individual cell is called a **torula.** Under the higher power of the microscope the yeast plant appears a small round cell with a very thin cell-wall and granular contents. The cell-wall is so thin that it cannot be seen definitely, until the protoplasm has been stained by some fluid like magenta. A few taps with a needle on the cover-slip burst the delicate cells, the coloured protoplasm emerges, and the crushed walls remain behind like empty grape skins. The granules and droplets in the protoplasm consist of protein material and of fat, and there are also usually present spaces of irregular size and shape, called **vacuoles,** which are filled with a transparent fluid. The nucleus is invisible in unstained specimens, or even in specimens stained by iodine and magenta. But more complicated methods and special stains reveal its presence. It is a small rounded body lying in the protoplasm of the cell and staining more deeply.

Yeast cells in the liquid from a brewer's vat are in a favourable position for growth, as they are in an abundant supply of food. Various stages of **reproduction** by **budding** (Fig. 1, *c*) are always to be found. A very young bud is a small protrusion of the protoplasm, covered by a protrusion of the cell-wall. As the bud grows, its wall gradually becomes round and finally closes off the bud from the parent cell. But the budding may take place so rapidly that a young bud begins to throw out buds itself before it has separated from the parent. Moreover, the same cell may give rise to more than one bud at the same time, so that little colonies of yeast cells are frequently found.

When the conditions are unfavourable for growth—as, for instance, when yeast is kept so long in a fluid that all the available nourishment has been used up, it prepares to tide over unfavourable conditions by another method of reproduction. In cells starved in this way, part of the protoplasm breaks down and the plant, in fact, feeds on itself. There results the curious paradox of cellular starvation, namely, that fat, due to the breaking down of protoplasm, is deposited in the cells. Then the nucleus breaks up into four and the scanty protoplasm becomes aggregated around each. There are thus formed four little round bodies which become arranged in a pyramid in the centre of the cell. Round each of these four a very thick cellular wall is deposited and they then form what are called **spores.** Ultimately the cell-wall of the parent cell is ruptured and the spores emerge. These are peculiarly able to retain their vitality under unfavourable conditions. They can survive an unfavourable environment which would destroy the ordinary torulæ. If the liquid dries up, the spores form a light dust which gets blown about, and so serves to spread the plant from place to place. They retain their vitality for long, and, as soon as they find their way to a nutritive fluid again, they develop rapidly into the ordinary form of the plant.

The formation of spores can be observed readily if some yeast be spread on a thin slab of plaster-of-Paris kept moistened with water under a bell jar, or if it be grown on a slice of potato or turnip.

The cell-wall calls for some special notice. It is composed, like the cell-wall of all other plants, of cellulose. This is a substance of which the exact formula is uncertain. The smallest formula is $C_6H_{10}O_5$, but it is probably more complex than this. Four of the oxygen atoms may be present in the hydroxylic form ($-OH$). In the fungal plants of which yeast is one, the cellulose appears in some way to be modified, for it does not give the ordinary reactions of the cellulose of green plants with Schultze's solutions until it has been previously specially treated. It is possible that in fungi it may be impregnated with some peculiar nitrogenous body. In order to verbally distinguish it from the cellulose of green plants it may be spoken of as **fungus-cellulose.**

The yeast plant, like some other low organisms, possesses the peculiar property of causing **alcoholic fermentation.** The "sweet-wort" from which beer is made is malt dissolved in water. Malt is made from grains of barley which have been allowed to sprout, and then killed by heating. In the process of sprouting a large part of the starch contained in the grain is turned into what is called grape sugar. This sugar, along with some of the protein material and the mineral salts contained in the barley, is dissolved in the wort. Yeast, placed in this, has the necessary food materials—sugar, mineral salts and protein—and it multiplies very rapidly. Large quantities of carbon dioxide are given off, the sugar gradually disappears, and alcohol is formed in the liquid. By careful experiment it has been shown that only about 1 per cent. of the sugar is used as food by the yeast-cells in their growth and multiplication, and the actual amount of carbon dioxide expired by them must be very small. But their presence excites a peculiar chemical change in the great mass of sugar, by which it is split up into carbon dioxide and alcohol. It is this carbon dioxide gas that is given off in such quantities that, if a little yeast be put in a teaspoonful of wort in a test-tube, in a few minutes the upper part of the test-tube will be so full of the gas that a burning match, thrust into it, will be immediately extinguished.

Chemically, the process of alcoholic fermentation excited by the yeast plant is as follows :—

$$\begin{array}{ccccc} \text{Grape Sugar.} & & \text{Alcohol.} & & \text{Carbon Dioxide.} \\ C_6H_{12}O_6 & = & 2(C_2H_6O) & + & 2(CO_2). \end{array}$$

It must be remembered that this is a side issue of the life of the plant : the alcohol and the carbon dioxide are not the direct result of the changes in the plant protoplasm. The yeast plant, like many other low organisms, is what is called a living or organised **ferment**. That is, as the result of its living activities it produces some body which has the power of acting upon sugar without itself undergoing any apparent change. Such a substance is a **ferment.** It can be obtained separately from yeast cells and exists apart from the living cell. Its action is even then exerted upon sugar. Thus alcoholic fermentation depends not upon the yeast plant as a living entity, but only upon the presence of the ferment formed by its living activities.

In brewer's wort, the yeast plant obtains its nitrogenous food in the form of protein. Pasteur has shown that protein is not necessary to its growth, but that a solution containing ammonium tartrate as the only supply of nitrogenous food is sufficient. Thus, yeast stands intermediate between the cells of green plants and the cells of animals. Like animals it will absorb protein directly ; unlike green plants it cannot build up protein when supplied with nitrogen in the simple form of nitrates. But, given the more complicated form of ammonium tartrate $(NH_4)_2\ C_4H_4O_6$ it can complete the elaboration of protein. M. Pasteur invented an artificial wort in which the yeast plant multiplies rapidly and sets up alcoholic fermentation.

Pasteur's Solution is as follows :—

Water, H_2O	83·76	per cent.
Cane sugar, $C_{12}H_{22}O_{11}$	15·00	"
Ammonium tartrate $(NH_4)_2\ C_4H_4O_6$	1·00	"
Potassium phosphate, K_3PO_4	0·20	"
Calcium phosphate, $Ca_3\ (PO_4)$	0·02	"
Magnesium sulphate, M_9SO_4	0·02	"
	100·00	

In this, fermentation goes on most actively at temperatures between 28° and 34° C.; at low temperatures it ceases; at 38° all growth stops. If the liquor be boiled, the plants are killed and the process is permanently arrested. The process goes on equally well in darkness or in light. It will occur in the absence of oxygen, so showing that the yeast plant is able to obtain its oxygen by chemical decomposition of its food. It can take up its oxygen out of a chemical combination, and does not depend as green plants and animals do upon free or uncombined oxygen for respiration. Free oxygen, dissolved in the solution, stops the process, and carbonic acid has no effect upon it. Thus in the yeast plant we have an organism remarkably independent of all conditions but its food, and, as all manner of food solutions have been tried and Pasteur's solution is found to be the most suitable, we can get a close knowledge of the process of life in this case. The water in the solution is needed directly, as a food for the plant, and indirectly that it may get its food in the suitable condition of solution. The sugar is not necessary to the life of the plant; it grows, although very slowly, if sugar be omitted from the solution, obtaining the necessary carbon from the ammonium tartrate; but sugar is required for active growth and to exhibit the power of the plant as an alcoholic ferment. The ammonium tartrate is necessary; without it, unless protein is directly supplied, all growth ceases. The three mineral ingredients—potassium phosphate, calcium phosphate, and magnesium sulphate—give the mineral constituents found in the ash of the yeast plant, which always contains potash, lime, magnesia, and phosphoric acid, while sulphur is given off in the process of burning. It is possible that calcium, potassium, and phosporus play some indirect part in assimilation, since their presence appears necessary to enable the protoplasm to assimilate nitrogen and carbon. If either one of them is absent, although every other constituent necessary as food is present, the plant will starve. This is true alike of fungi and green plants.

CHAPTER V

UNICELLULAR PLANTS (*continued*)

BACTERIA

IF a drop of water on a slide be stirred with a paint-brush dipped in gamboge, and the drop be then covered with a slip, and examined under a high power of the microscope, the exceedingly minute particles of the gamboge become visible. These minute particles are not at rest, but ceaselessly vibrate to and fro, each within a space about two or three times the size of the particle. Such "**Brownian movements**" can be observed in all minute bodies suspended in a fluid, and one must distinguish carefully between them and actual vital movement, in any organisms that are small enough to show them.

All animal and vegetable substances that are rotting swarm with the minute organisms known as **Bacteria** or **Microbes.** A drop of milk or soup that has "gone bad," or a little of the soft matter scraped from a decaying potato or from a hyacinth bulb in water that has begun to smell instead of to sprout, all show under the microscope innumerable minute bodies just on the border-line of invisibility, and, like the grains of gamboge which they resemble in size, vibrating to and fro. When the eye becomes accustomed to their minuteness it is seen that while some merely vibrate, others actually progress through the fluid. Some are round, others oblong, straight or curved, thin or thick, and many are arranged end-to-end in threads or spirals. It is perfectly clear that in such cases there is a collection of organisms with different shapes and sizes, with different habits and movements. Until a method had been invented by which the forms of bacteria could be sorted out, and studied by themselves, no exact information was possible. Now that it has been discovered, the best of these methods seems very simple. A gelatinous preparation in which bacteria will grow abundantly, but which has been boiled to kill any already in it, is melted, and a drop of the fluid containing the bacteria is shaken up with a small quantity of the liquid jelly. A drop of this is shaken up with another quantity of the jelly, and this process may be repeated several times. As bacteria are much smaller than $\frac{1}{10000}$ inch, a million might easily be present in the small drop taken. Suppose the quantity of jelly to be 100 times the size of the drop, a drop taken out of this would contain about 10,000 bacteria. A second dilution would reduce the number to 1,000, a third to 10. The jelly in a liquid condition is poured upon a glass plate and cooled in a very thin layer. The ten bacteria (in this hypothetical case) are fixed here and there in the jelly. When the plate is kept in a suitable place the bacteria begin to multiply, each giving rise to a colony like itself, and these colonies grow quite large enough to form patches visible to the naked eye. The colonies of different bacteria can be identified by their shapes and colours, by their modes of growth in different media and so forth, and "pure cultivations"—*i.e.*, cultivations containing only one kind of bacterium—may be made by inoculating jellies from the various colonies on the first mixed plate. By such methods an enormous number of different microbes have been studied. They all consist of a delicate cell-wall, in most cases formed of fungus-cellulose, which encloses protoplasmic contents. These yield a peculiar nitrogenous body, devoid of sulphur, phosphorus, and oxygen, and consisting of carbon, hydrogen, and nitrogen. It is called myco-protein. These contents stain deeply with the kinds of stains that colour the nuclei of larger cells, and no distinction between protoplasm and nucleus has been made out in them. Some microbes have at one end or at both a delicate vibratile **flagella**, by the movements of which they are driven or pulled through the water. These flagellæ, however, are not like those in other plants and animals, namely, processes of the protoplasm, but they appear to be derived from the cell-wall. They are thus fundamentally of a different nature to other flagellæ. Some bacteria are apparently motionless, save for "Brownian movement."

Definite names have been given to some of the most common shapes in which microbes appear (Fig. 6). Thus, minute round forms are called **Micrococci**; larger round forms, **Macrococci**; oblong forms not twice as long as they are broad are called **Bacteria**; oblong forms more than twice as long as they are broad are called **Bacilli**; a flattened, spirally-twisted form is called **Spiromonas**. When food is abundant and the conditions of life favourable, bacteria increase in length, and by repeated division across the long

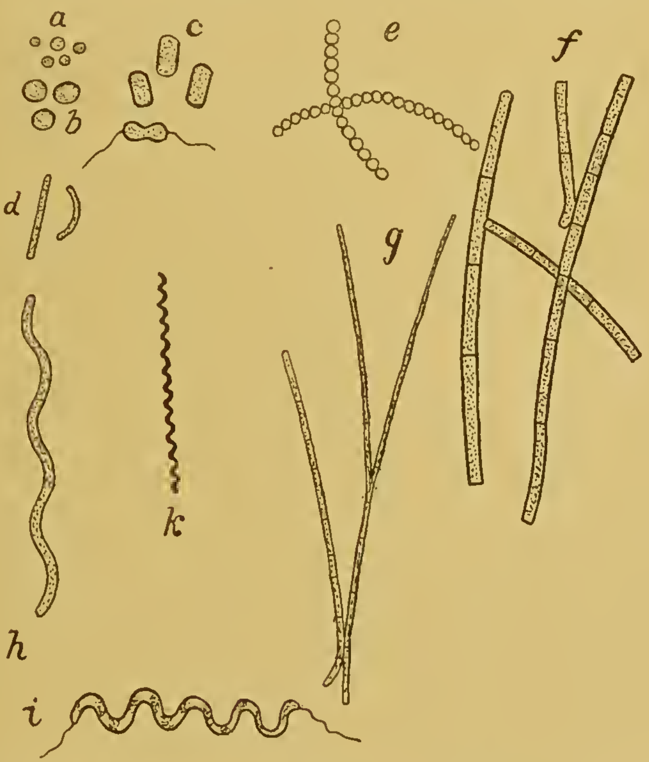


FIG. 6.—Forms of Bacteria. a. *Micrococci*. b. *Macrococci*. c. *Bacteria*. d. *Bacilli*. e. *Streptococci*. f. *Leptothrix*. g. *Cladothrix*. h. *Vibrio* i. *Spirillum*. k. *Spirochaete*.

axis form jointed filaments or threads. When micrococci reproduce in this way they form **Streptococci.** Unbranched threads are called "**Leptothrix.**" Where occasional longitudinal division occurs and so branches are formed, the filaments are termed **Cladothrix.** When the filaments are short, with slight undulating curves, the name **Vibrio** is applied, while **Spirillum** consists of short, rigid curves, twisted like a corkscrew. **Spirochaetes** are long, thin filaments with the individual curves short and slender.

There are many other forms, and considerable doubt exists as to how far microbes with definite history and properties can be identified with individual shapes.

When food is scarce or the conditions of life unfavourable, reproduction by spore formation occurs. The protoplasm becomes granular, a small bright spot appears in it, and this spot increases in size until it may bulge out the wall of the cell. Spores may be round, ovoid, or rod-shaped. They are always colourless, but are very bright when seen by transmitted light. They have an exceedingly thick, firm wall, and are liberated by the decay of the cell in which they were formed. Occasionally spores are formed by fission ; in a dividing chain or filament here or there are formed large spores called **Arthrospores**, because of the jointed appearance given to the filament in which they appear.

These spores are the great means by which microbes survive unfavourable conditions, and spread from place to place, until, reaching a situation where moisture, temperature, and food are satisfactory, they give rise to the vegetative, rapidly multiplying form.

Innumerable quantities of spores are formed : they may be blown about as a fine dust by the air, or may be carried by currents of water. They will remain undeveloped for practically an indefinite time, if no favourable conditions occur.

Under ordinary or favourable conditions bacteria multiply by **fission**. In this process a septum is formed across the cell, splitting the protoplasm into two parts. Then division and separation of the cell into two takes place through this septum, and two bacteria are thus produced. These grow and repeat the process, and this goes on so long as external conditions are favourable. It is an extremely rapid mode of multiplication, and several millions may be derived from a single one in the course of a short time.

In air, in water, in drains, in the soil, in the dust, in crevices between the planks of floors, they are always present. They are light enough to be wafted about by currents of air, but in a still or windless place they gradually sink to the ground. Thus, in the morning, when a room has been quiet all night, there are few in the air ; after the housemaid has disturbed things by sweeping the floor, they are to be found in abundance. In the air of a well-flushed culvert few are present ; when the flow of water gets low they reach the air from the dry crust deposited on the sides uncovered by water. It should be remembered, however, that the great majority of bacteria are not only harmless, but play a necessary and beneficent part in Nature.

Most microbes live on organic substances and are unable to build up their protoplasm out of inorganic materials. In this respect they resemble yeast and differ from the green plants. Hence the vast majority of them flourish in decaying organic matter, in the bodies of animals or plants, or in the soil. A few, however, are known to contain chlorophyll and to live like *Protococcus*. Disregarding these exceptional forms, microbes can be divided into two classes, those like the yeast plant, that can obtain the oxygen needed for all living protoplasm from chemical compounds, and those that require a supply of free oxygen. The first class are called **Anaërobic,** as they are independent of free oxygen, the second, **Aërobic,** because they require it. The green microbes require light ; most microbes live either in light or darkness, but are killed by direct exposure to sunlight. The conditions of heat are more complicated. Actual subjection of protoplasm to a heat very little under boiling-point certainly kills all microbes ; but some microbes, and the spores of most, can resist heat so well that even a considerably prolonged exposure to temperatures above boiling-point does not kill them. In such cases, however, it is probable that the wall of the microbe or the spore prevents the protoplasm within it from actually reaching a high temperature. Freezing arrests the growth of all microbes, but even continued exposure to such a temperature does not kill them. Thus ice made from water containing microbes contains them in a condition only of arrested vitality ; when the ice melts, the suspended organisms begin to multiply. Generally speaking, microbes flourish best at a temperature between 30° and 40° C., but the most favourable temperature is different for different forms.

Microbes are associated with many of the processes of everyday life. The most obvious, and perhaps the most important, is their association with **putrefaction.** If an organic substance—for instance, soup—be boiled for some time and exposed to the air, it slowly begins to putrefy. A scum forms on the top, and this can be seen to consist of many microbes embedded in a layer of jelly (zooglœa). The liquor becomes turbid and gives off an evil smell : examination of it shows that microbes abound. After a certain length of time it becomes clear again : green organisms appear in it and putrescence has ceased. On a large scale this process goes on everywhere in the world. Microbes serve to break down organic matter into inorganic; to clean up the *débris* of the organic world, and so to prepare the way for fresh cycles of life. On the other hand, if some of the boiling soup be placed in a vessel that has been itself boiled, and so freed from microbes, and if the mouth of the vessel be plugged with cotton wool (previously baked for some time to kill microbes), no putrefaction will occur, and no bacteria will be found in the fluid. Putrefaction occurs only when microbes get access to the substance ; if any air that may reach the substance be filtered through cotton wool, the spores of microbes present in the air are kept behind, entangled in the meshes of the wool. But so omnipresent are spores, that the slightest fleck of dirt, the use of a dirty instrument, or exposure to the air in the act of pouring out the hot liquor, may allow the entrance of spores or microbes and cause putrefaction.

Microbes are associated with many kinds of **fermentation.**

Thus, some, like yeast, cause alcoholic fermentation ; others turn milk sour by causing the formation of lactic acid ; others cause the formation of acetic acid from alcohol—*i.e.*, "sour" wine by turning it into vinegar. Many that live in the soil perform useful functions. Thus one microbe aids the transformation of ammonia into nitrous acid : another turns nitrites into nitrates ; and thus these two prepare necessary food for plants by turning ammonia, which the roots of plants do not absorb, into nitrates, which they do absorb. Another set of microbes live in little colonies on the roots of some forest trees and of common pod-bearing plants like peas and beans and vetches. Such plants, by the aid of the colonies of bacteria, are able to make direct use of free nitrogen, whereas most plants cannot make use of it. Thus, in what farmers call green manuring, if a green crop of wheat or oats be ploughed into the soil, the decay of the plants adds no nitrogenous richness to the soil, for all the nitrogen in these plants has been taken by them from the soil. On the other hand, if a crop of green vetches or of beans be ploughed in, the soil is enriched in nitrogenous compounds, for beans and vetches, by the aid of the bacteria on their roots, have made use of the free nitrogen of the air.

Some microbes are the cause of disease in man and animals. In certain cases the multiplication of the particular microbe within the body causes mechanical injuries ; capillaries may be blocked up, cells and tissues may be broken down. In others, the microbes form some kind of poison which, carried through the body by the blood, arrests or disorders functions by action on the nervous system. It has been noticed that the poisons set free by such microbes, or anti-bodies excited in the blood by the presence of these poisons, are fatal to the microbes themselves, or may neutralise their poisonous products, and, if death of the body affected does not occur in the interval, diseases due to microbe poisoning may run their course and then cease by the actual poisoning of the microbes themselves. An animal that has survived an attack of this kind is frequently **immune** to further attacks, and from this starting-point many attempts at preventive inoculation have been made. It has been found that if disease-producing microbes are cultivated for several generations in special substances, they are altered so that the microbes themselves or the poisons they give out, when introduced into the body of an animal, cause a change in the animal body not nearly so disturbing and dangerous as the changes produced by the uncultivated microbe, but yet equally efficacious in preventing subsequent attacks of the uncultivated microbe. Among the leading diseases associated with or caused by microbes are tubercle, tetanus, anthrax, plague, diphtheria, cholera, typhoid. But the relation between microbes and diseases is now in itself a great branch of science, and continual additions to the list of cases are being made.

On the other hand, many microbes normally present in the body are harmless or useful. A large number present in the alimentary canal aid the process of digestion, while others are harmless parasites.

CHAPTER VI

UNICELLULAR PLANTS (*continued*)

GREEN PLANTS

PROTOCOCCUS[1]

THE bark of trees and the surfaces of palings are frequently covered by a green layer, which comes off as a green powder if the finger or sleeve of one's coat be rubbed against it. Shake a very small quantity of this green powder on a glass slide; cover with a drop of water and a glass cover-slip, and examine under a higher power of the microscope. The powder will appear as a number of cells with green-coloured contents, occurring sometimes solitarily, but more often in groups of two, four, or more (Fig. 7, *a* and *b*). This occurrence in groups is due to division; the plant has been feeding and growing actively, and division of a cell into two, and of each of the two into another two, is in active progress. The daughter cells gradually become rounded and separate from each other, and various stages in this process may be observed. Select a single large cell for special examination. The cell is surrounded by a definite transparent cell-wall sufficiently thick to show a double contour. The green contents of the cell are not perfectly uniform, but the green colouring matter (chlorophyll) is confined to a number of small, irregular bodies, named **chromatophores** or **chloroplastids.** These are tightly packed together, and fill up the greater part of the cell; but here and there, especially in the centre and round the circumference, the clear transparent cell-protoplasm, in which they are embedded, may be observed. If a few drops of iodine solution be run under the cover-slip, the chromatophores and the protoplasm become more distinct, and, towards the clear central space, the nucleus, a small, semi-opaque body almost invisible before, becomes apparent. The cell-wall, like the nucleus and protoplasm, is tinged pale brown by the iodine. If some cells be allowed to soak in strong iodine solution for a few minutes, and then be transferred to sulphuric acid (5 per cent. solution), the brown of the wall turns to a dark blue. This is a characteristic test for a substance closely allied to starch and sugar, called **cellulose,** which forms the cell-wall of most plant cells. Or, if the cells are treated with chlor-zinc-iodine, sometimes called Schultze's solution, the protoplasm and nucleus stain brown and the cellulose purple or purplish-blue.

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[1] The name *Protococcus* has been applied both to the resting and to the motile phases of two plants:

Pleurococcus vulgaris.

Synonyms—*Protococcus vulgaris.*
Protococcus communis.
Hæmatococcus vulgaris.

This is the green alga occurring abundantly on the bark of trees, old palings, &c. It has a resting and a gonidial phase; the latter, when in water, is ciliated, and both red and green colour may occur in the same plant, streaked or aggregated.

Protococcus pluvialis, Kutz. = *Chlamydococcus pluvialis*, Br.

This is a very variable plant occurring in water, and having a motile generation usually succeeded by an indefinite number of quiescent forms. It is usually relegated to the *Volvocineæ.*

The quiescent stage obtained from bark, &c., is *Pleurococcus;* that from water is *Protococcus:* the motile stages in water may belong to either.

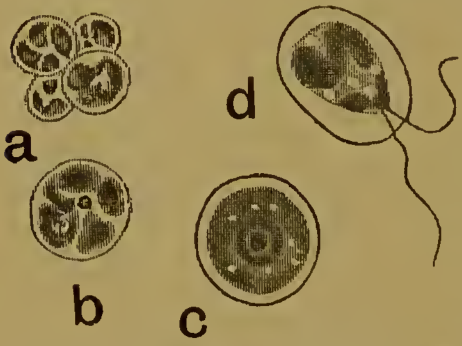

FIG. 7.—**a** and **b**. *Pleurococcus*. **a.** Four cells in the natural condition much enlarged. **b.** Single cell stained to show the nucleus in the centre surrounded by the chromatophores, which are separated from the cell-wall by a short space. **c.** Resting Stage. **d.** Motile Stage of *Protococcus*, showing pyrenoids as white spots.

When these green cells are kept in rain-water, exposed to light, for some days, they give rise to a motile form. Drops of the water, taken from time to time, should be examined under a cover-slip with the higher power of the microscope until small green cells, actively moving about, are observed. In these the cell-wall is thinner, and the chloroplastids, compared with the colourless protoplasm, have a smaller bulk than in the resting phase. The cells are slightly elongate, and move with the narrow end forwards. At this end a pair of delicate processes, nearly invisible until the cell has been killed and stained by iodine, protrude from the protoplasm through the cell-wall. They are termed **cilia,** and it is by their rapid twisting vibrations that the cell is screwed or pulled through the water.

In the mud from a rain-gutter, or in the semi-liquid scum from a rain-water tank exposed to air, a similar plant, also commonly called *Protococcus*, is abundant. Some of this mud or scum should be mixed with a small quantity of water, and drops of the fluid examined in the same manner as the green powder from the bark. Among the many small organisms present, there may be a number of isolated round cells, coloured green or red, and possessing a thick cellulose cell-wall (Fig. 7, *c*). The contents consist of protoplasm, chromatophores, and a nucleus. These cells are the resting stages of *Protococcus*. The colour of the chromatophores usually is green, and is due to chlorophyll; but it may also be red, or green streaked with red. The red colour is due to a pigment called **hæmatochrome;** but apparently the use of the pigment, whether red as hæmatochrome or green as chlorophyll, is identical. Embedded in the chromatophores are numerous small ovoid bodies, which catch the light sharply if the mirror under the microscope be flashed to and fro. When the plant is treated with iodine, these bodies stain a dark blue. They have been found to consist of a protein substance, covered by a thin layer of starch, and are called **pyrenoids.** They do not occur in the green plant obtained from the bark of trees.

Occasionally the protoplasm of the resting-cells may be seen to be dividing within the cell-wall. It breaks up into two, and then into four, and then the cell-wall disintegrates, and the results of division emerge as tiny elongate cells, which move actively about. But if the actual process of division be not seen in the water containing the resting forms, resulting motile forms are certain to be noticed (Fig. 7, *d*). These move steadily through the water, with one end directed forwards. In the active condition, the chief difference from the resting condition appears to be that the cell-wall is very thin, and is some distance from the coloured contents. Sometimes this wall is not acquired until after the liberation of the motile cells. The division of the parent cell into four is not always constant. It may divide into eight. The resulting daughter cells are then smaller, and at first are always naked and have no cell-wall. *Protococcus* is thus dimorphic in its reproductive cells, having a larger **macrozooid** form and a smaller **microzooid**. These motile forms may pass into the resting stage. Their formation enables the plant to multiply and spread itself. It is a method of **asexual reproduction.** If a drop of solution of iodine be added to the water, movement becomes slower and finally ceases. The cause of the movement can be seen in two long thin colourless threads, each larger than the length of the cell. These "**flagellæ**," or "**cilia**," project from the cell contents at one end, cross the interval between the cell contents and the cell-wall, and project through that, and by their waving vibrations pull the zoospores through the water.

However long *Protococcus*, in any of its forms, be watched, it is never seen to take in or to pass out any solid particles. The firm structure of the cell-wall would render this impossible. It must live on substances either in a state of solution in water or in a gaseous condition. Either directly from the air or from the rain-water, in which a certain quantity of air is always dissolved, *Protococcus* has access to oxygen, carbonic acid, and nitrogen. The rain-water in which the motile phases live, or the damp situations where resting phases occur, contain nitrates, ammonia, frequently common salt, and small quantities of sulphates and phosphates—chiefly of lime. Thus all the materials for protoplasm are present; and as *Protococcus* grows and multiplies, it has the power of building up protoplasm from them. When a quantity of *Protococcus* is exposed to sunlight in, for instance, a very slender test-tube filled with water and inverted in a saucer of water, bubbles of gas are given off; and when a sufficient quantity has been collected, the gas may be proved to be oxygen. This oxygen comes from the carbon dioxide of the air, which, after entry into the plant in a state of solution, is decomposed by the chlorophyll in the presence of sunlight, the plant retaining CO, and giving off O_2. The stages in the combination of the carbon into proteins and protoplasm are largely matters of theory. Many simple compounds of carbon, hydrogen, nitrogen, and oxygen occur in plants, and these may be stages in the elaboration of protoplasm. But protoplasm *is* formed, for *Protococcus* grows. It is not even certain where the nitrogen comes from. In the majority of green plants the nitrogen of the air is not made use of directly, but is obtained only from salts—chiefly nitrates, present in water or in the soil. Some plants do make use of free nitrogen, in an indirect manner, and with the aid of commensal organisms associated with them.

It is by the breaking down of protoplasm that energy, absorbed from sunlight through the agency of chlorophyll, is liberated for the vital processes of the plant. And so there are to be found in cells like *Protococcus* various substances derived from protoplasm, but with a simpler structure. Some of these are clearly useful. The cellulose cell-wall is very indestructible, and protects the delicate protoplasm and gives it some rigidity. The pyrenoids may serve as a store of nutriment and as centres in which starch is formed. When the plants are in darkness, they are unable to decompose carbonic acid, and—certainly in the case of higher plants—starch, formed in sunlight, disappears in darkness. There are also nitrogen-containing substances formed by protoplasm, and these substances appear to be harmful if retained within it. Where a pulsating vacuole exists, it serves for their removal in a state of solution in water. In other cases they pass out through the cell-wall, or are stored up as concretions.

Without attempting to go into obscure and disputed details, one may lay down that oxygen is used in these changes of protoplasm, and that more oxygen is combined with the substances formed by protoplasm than with the substances of which protoplasm consists. In other words, the processes of life take place by an oxidization of protoplasm. The oxidized substances are the metaphorical ashes of the furnace ; some of them, because they choke the fire, must be removed ; some may be turned to account, as, for instance, to strengthen the walls of the furnace ; others—those which are not completely burnt up—may be stored to use when fuel is difficult to obtain. The removal of purely waste substances from protoplasm is called "excretion" ; the formation of useful substances is called "secretion" ; but these two grade into each other, and probably all secretions were at first excretions. Among the chief excretions of protoplasm are water and carbonic acid. In the case of green plants, the protoplasmic excretion of carbonic acid and absorption of oxygen during sunlight is disguised by the greater converse activity of chlorophyll—using up carbonic acid and discharging oxygen.

CHAPTER VII

SIMPLE MULTICELLULAR PLANTS

SPIROGYRA

MANY other green plants live under conditions similar to those of *Protococcus*. In summer, ponds and lakes and fresh-water streams gradually become fuller of them. In fresh water which is moderately clear, among the floating green weeds one may pick up handfuls of delicate green threads, which feel silky and slippery. Among these green threads it is easy to pick out with the microscope the plant known as *Spirogyra*. For that plant has the chloroplastids, to which the colour is due, in the form of spiral bands wound round and round within the colourless thread. The thread consists of a number of cylindrical cells of different lengths, arranged end to end (Fig. 8, *a* and *b*). The plant is therefore not unicellular, but multicellular. It differs, however, from the higher and more complex multicellular plants, or Metaphyta, as they may be called, because its cells are arranged in one direction in space, instead of two or three. The plant body is thus not layered or massive, but is filamentous. The threads never branch, and the diameter is constant along the thread. Except for difference in the length of the cells, the thread, whether long or short, has the same appearance throughout its length. The threads are unattached and motionless, forming floating masses in water. The cell-walls are of cellulose and are colourless and transparent, and a common wall separates cells lying next each other in the threads.

The spiral bands vary in number, and in the tightness of the coils, in different species. Some species have two bands, twisting in opposite directions. They are similar in nature to the green masses in *Protococcus* and like them are **chromatophores** or **chloroplastids**—masses of protoplasm impregnated by chlorophyll. Embedded in the chloroplastids are a varying number of clear bodies like crystals, consisting of a central protein substance covered by a layer of small starch grains. The central body is a **pyrenoid**. In cells where the green coils are loosely arranged so that they do not obscure the rest of the cell, streaming **threads of granular protoplasm** may be seen, as in *Tradescantia*, passing from a central body of protoplasm containing a **nucleus** to a thin layer lining the cell-walls. Other streaming threads pass from the

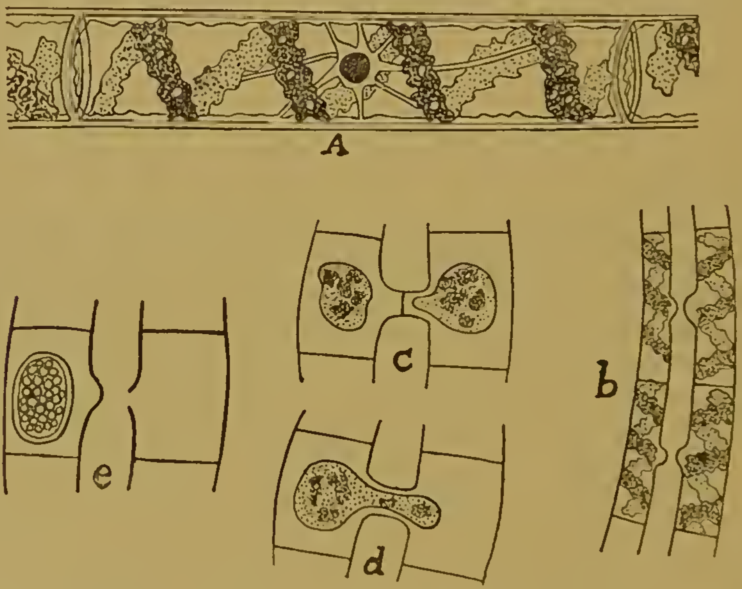

Fig. 8.—*Spirogyra*. **a.** Part of a filament highly magnified showing a single cell with the ends of adjoining cells. The cell-wall is lined by a thin colourless layer of protoplasm from which threads run to the protoplasm surrounding the nucleus and to the chromatophore, which is a green band wound round the interior of the cell and containing pyrenoids.

b, c, d, e. Stages in conjugation. **b.** Adjoining filaments with hollow processes of cell-wall growing out from opposite cells. **c, d, e.** Two cells in which the chromatophores have broken up and the protoplasm has aggregated into lumps; at **c** and **d** the protoplasm of one cell is passing into that of the other; at **e** the protoplasm of both cells has fused to form a spore in one of them, which has become surrounded by its own cell-wall.

nucleus to the chromatophores. Treatment with re-agents is necessary to complete the examination. If solution of iodine be run into the water under the cover-slip, the starch grains surrounding the pyrenoids are stained blue ; the protoplasmic threads and the nucleus become tinged with brown. Iodine and sulphuric acid, by tinging the cell-wall blue, and chlor-zinc-iodine by staining it purple, show that, as in *Protococcus* and in most vegetable cells, it is composed of **cellulose**.

Very often the protoplasm lining the cell-wall is invisible, while the cell is alive. If a 10 per cent. solution of common salt be run under the cover-slip, water is extracted by osmosis from the cell contents, and the protoplasm shrinks, leaving a clear space between itself and the cell-wall. A cell in this condition is said to be **plasmolytic.**

Protoplasm is so colourless that it is not seen readily under the microscope. It contains many substances which are different in their functions and chemical and physical properties, but which, at least in the living cell, cannot be distinguished. For these reasons, elaborate methods of **staining** are required for microscopical investigation. The methods are complicated and very numerous, but they depend on the fact that the different substances, however alike in appearance, have physical or chemical differences which cause a difference in the kind or amount of colouring which is absorbed from stains. A great part of microscopical work consists in the careful selection and application of stains, to pick out the slightest differences in the protoplasm. But simple methods will show much. If some *Spirogyra* be placed for twelve hours in a saturated solution of picric acid, the protoplasm is killed and hardened ("*fixed*" is the technical term), and the chlorophyll is dissolved out. The threads, or small pieces of them, should then be washed thoroughly in distilled water to remove the acid, which has done its work. The threads will now readily be coloured red by a solution of borax carmine. When they have been soaked for nearly an hour in this, they should be placed for a few seconds in alcohol slightly acidified by hydrochloric acid.[1]

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[1] Two to four drops of acid to every 100 c.c. of 70 per cent. spirit.

The acid-alcohol appears to dissolve out the greater part of the stain, but it has a stronger action upon some parts of the protoplasm than upon others. The acid-alcohol must be washed out with neutral alcohol and pieces of the stained plant may be examined on a slide in a drop of glycerine, covered by a slip. It is more satisfactory to substitute some better mounting medium than glycerine. To do this, omit the glycerine stage and place a small piece of the thread in 70 per cent. alcohol on a slide; soak up most of the alcohol with the edge of a piece of blotting paper; replace it by stronger (85 per cent.) alcohol; and after a few minutes' soaking replace by absolute alcohol: after a similar interval replace by oil of cloves or chloroform: and finally replace by canada-balsam dissolved in benzine or chloroform. A cover-slip having been placed on the balsam while it is still liquid, the benzine or chloroform slowly evaporates and a permanent transparent preparation has been made.[1]

In such a preparation the protoplasm is tinged pink. It can be seen to consist of a layer lining the cell-wall and connected by strands with a central mass of protoplasm. This again is connected by strands with the spiral protoplasmic bands, which, impregnated during life with chlorophyll, composed the chromatophores. The protein part of the pyrenoids is stained darker red, and the nucleus also is stained more darkly than the rest of the protoplasm. In a young cell the protoplasmic layers and strands are larger relatively to the size of the cell, than in an older cell. The cell, in fact, seems to be filled with protoplasm in which there are irregularly placed cavities. In the living condition the cavities are filled with cell-sap, a watery solution containing sugar and various soluble bodies. As the cell grows older the cavities or vacuoles increase in size, and the strands and outer layer become thinner and thinner until the adult condition is reached. In that condition the thin layer of protoplasm lining the wall is called the **primordial utricle.**

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[1] The balsam will set more rapidly, in a day or two, if the slide is placed in a water oven at 50°–60° C.; otherwise, several months may be needed.

In the stained specimen it may be seen that the nucleus is a biconcave disc so placed that the faces of the disc are parallel with the ends of the cell. The shape of the nucleus varies in the cells of different plants or animals, in different kinds of cells in the same organism, and even in the same cells at different times. Within the nucleus, extremely minute darkly stained particles are visible. The presence within the nucleus of a substance which stains more deeply than the protoplasm is invariable in plants and animals, and this substance from its greater capacity for absorbing stains is named **chromatin.** The chromatin may be arranged as a coiled band, in nodules, or in particles so fine as to elude observation. In addition to the chromatin, a larger body not staining so intensely is also present. This is called the **nucleolus.** During the division of cells, definite and striking changes occur in the arrangement of the chromatin, and there is strong reason for believing that this substance is the seat of many important properties of cells, and especially those properties that give cells their individual features. If, for instance, the chromatin of two kinds of *Spirogyra* could be interchanged, it is very probable that those differences by which we distinguish the kinds of *Spirogyra* would also be interchanged. As we shall see later, the chromatin is concerned specially in sexual reproduction, in which process cells from two parents combine to form a new individual.

By day, *Spirogvra* like *Protococcus* rapidly assimilates food, and at night, if the temperature is not too low for vital processes to go on actively, the starch grains formed by day disappear, and an exceedingly active growth of protoplasm takes place. When cells have reached their maximum limit of size they divide. By artificially keeping the temperature low at night, this change may be retarded until morning, and may thus conveniently be studied. First, the nucleus divides, going through a complicated process known as Karyokinesis (see Chapter XXVII), and the two daughter nuclei withdraw from each other towards opposite ends of the cell. Then the protoplasm of the cell, with the chloroplastids, divides in two, and in the middle of the cell a new cell-wall gradually grows in all round the cylinder, finally completing itself at the centre and separating the two halves of the protoplasm and the two daughter nuclei, so that there are two cells in place of the original cell. In the nuclear division the chromatin so behaves and distributes itself, that a very fair division takes place between the two cells, and no distinction can be drawn between them. Both carry the same kind of chromatin contents, and on the assumption that it is this substance which transmits and carries the characters of a cell, both cells resulting from the division must be regarded as identical. And, indeed, as far as we can judge, they are identical.

All the cells in the thread are capable of division, and so the thread may become very long. But, however many cells it may contain, the cells remain alike. The growth of all animals and plants which consist of more than one cell takes place by cell multiplication. In adult tissues the multiplication for the most part is, as in *Spirogyra*, a division into daughter cells exactly like the dividing cell.

Cell-growth and **cell-division** in *Spirogyra*, then, take place when conditions are favourable; when daylight is long and the assimilation of food rapid, and when the nights are not too cold, the ponds and lakes rapidly fill with the green weed. But when the heat is too great so that the water is evaporating, or when food is insufficient, in fact, when conditions are unfavourable, another process takes place. In a mass of *Spirogyra*, under such unfavourable conditions, one may feel that some of the threads are tangled and gritty. Under the microscope it may be seen that here and there, in the tangled mass, connections between the cells in different threads exist. A little search reveals various stages in the formation and result of these connections (Fig. 8, *b*, *c*, *d*, *e*). In threads lying parallel to each other, opposite cells send out blunt rounded processes of protoplasm covered by the cell-wall towards each other (Fig. 8, *b*). The whole of the protoplasm in each cell shrinks from the cell-wall and becomes rounded (Fig. 8, *c*). The two processes meet, the piece of cell-wall between them disappears, and the protoplasm from the cell that becomes round more rapidly leaves its own cell, creeps down the connecting-tube and fuses with the protoplasm of the other cell. The nuclei and the protoplasms completely fuse. The new mass of protoplasm remains rounded ; a very thick stratified cell-wall forms, and the resulting body is a resting **zygote** or **zygospore.** The wall is composed of three layers, of which the inner can resist water. The starch in the protoplasm is absorbed, and oil globules slowly appear in the protoplasm. It can resist the action of untoward influences much longer than the cells of the plant. The thick wall protects it against drought or cold, and it is this form that survives through Winter. In Spring, or in favourable conditions, the outer coats rupture, and the protoplasm, protected by the inner layer, grows into a *Spirogyra* thread of the ordinary vegetative kind. Thus a new individual arises and another generation comes into being.

This union of the protoplasm of two cells under unfavourable conditions is called **conjugation,** and it is a process of frequent occurrence among unicellular plants and animals. At first sight the utility of the process seems to consist in the union of the forces of the two cells, to resist the drought or cold, or starvation period. But another consequence of far-reaching importance follows. The resting-spore, or cell resulting from the union of the two cells of these separate individuals, unites the slightly varying qualities of the two. If there were a method of rejecting or rendering latent the worse half of each and expressing in the new individual the better qualities of the two it would result that the new individual would be an improvement on either of its predecessors. For in Nature no two individuals, even of the same species, are identical. There is some reason to suppose that in some cases at least this happens. It is, however, a well-ascertained fact that before the nuclei of the conjugating cells fuse, a part of the chromatin of each nucleus is turned out, and only the remainders actually fuse. In the formation of a new individual by this **sexual process** of reproduction, it is clearly possible that new combinations of hereditary characters can thus take place. Something is lost from one cell, and something else from another, and the new individual, while yet carrying all the specific characters, differs from both parents in its particular combination of individual characteristics. It is difficult, of course, to appreciate this in a simple plant like *Spirogyra*, where individual differences are subtle and inappreciable. But to think the problem over in this species helps us to understand the problem in more individualized forms, such, for instance, as Man. If, as is probably true, the chromatin is the bearer or carrier of the chief tendencies or characters of the cell, it is clear that the nucleus of the new cell contains tendencies coming from both conjugating cells. Among the multitude of threads growing out from resting spores formed by conjugation, even if the parts of chromatin selected and rejected were selected and rejected by chance, a very large number of different combinations would result. In the subsequent struggle for life, where the struggle is so finely drawn that the slightest advantage or disadvantage determines the elimination or survival of an organism, the most suitable combinations would succeed best ; the least suitable would perish soonest. And so conjugation may be a method of securing individual **variation,** and by natural selection operating among the varying forms it may lead to the persistence of improved or altered forms of organisms. In that way, new species may arise.

There is yet another feature of interest connected with conjugation. In many cases the conjugating cells are absolutely alike. In *Spirogyra*, however, the protoplasm of one cell remains stationary within the cell-wall ; the protoplasm of the other cell, leaving its own wall, bodily migrates into the first cell. In some plants and in many animals, the migrating-cell, instead of merely passing down a short tube from cell to cell, wanders away from its place of origin until it finds, perhaps at some distance, a cell which is ready for conjugation. **Sexual reproduction** in higher plants and animals is really a conjugation of this kind. The motionless cells are the **egg-cells** or **ova**, and usually they remain quiescent within the tissues of the female which gave rise to them; the motile cells are the **spermatozoa**, which, after they have left the male, have to reach and conjugate with the ova. Exactly as in the conjugation of simple forms of life like *Spirogyra*, the new individual formed by the combined ovum and spermatozoon shares characters coming from both parents; and exactly as in *Spirogyra*, before conjugation takes place, part of the chromatin is ejected by the ovum and spermatozoon.

Spirogyra, then, is a simple plant, living like *Protococcus* on inorganic substances in solution in the water in which it lives, and building these substances into protoplasm by a complicated process in which chlorophyll and sunlight take a chief share. Unlike *Protococcus*, the cells resulting from vegetative division, although all alike, remain attached to each other. But it has, in addition, the process of conjugation, which foreshadows the sexual reproduction of higher organisms.

The interesting question now arises whether we are to regard *Spirogyra* as a colonial Protophyte, that is, a unicellular plant in which the products of cell-division remain attached to each other, or whether it is a simple form of multicellular plant. If it were an animal instead of a plant, the undifferentiated nature of its body would cause it to be placed among the colonial unicellular forms. An animal is not regarded as a Metazoan simply because it is made up of many cells; these cells must be differentiated into at least two distinct kinds of tissues, and a definite embryological development must be passed through. But the early embryology of plants does not present the same constant fundamental features which that of animals does, and consequently cannot serve the same purpose in helping us to decide the alternative question as to whether a given plant is a colonial Protophyte or a simple Metaphyte. The question, therefore, with regard to *Spirogyra* may be left an open one. It is a Metaphyte so far as it consists of many cells; it is a Protophyte so far as these cells are all alike and each one performs by itself all the functions of life. In which class we shall place it depends upon the width of our definition of either class.

CHAPTER VIII

SINGLE-CELLED ANIMALS—PROTOZOA

AMŒBA

ALTHOUGH most of the plants with which we are familiar consist of a multitude of cells specialized for different purposes and arranged in different ways, there are many plants, like *Protococcus* and the yeast plant, each of which consists of a single cell. So also with animals ; all the larger animals consist of a large number of cells specialized for various purposes and arranged to form different tissues and organs. But there are very many animals grouped together by zoologists under the name **Protozoa**, in each of which a single cell may form the whole animal. These simple animals abound in nature ; any drop of stagnant water may contain many of them ; they are to be found in pools and ditches, in lakes and rivers, on the bottom of the sea and on its surface, and in the slime and mud of the shore. If some fluid containing organic matter be exposed to the air, single-celled animals will appear in it almost as soon as bacteria, reaching it from the air in the same way as bacteria reach it. Many of them live as parasites in the bodies of animals or of plants. If the contents of the rectum of almost any animal that lives in water (as, for instance, a water-beetle or a frog) be examined under the microscope, many protozoa will usually be found. Other protozoa live in the body-cavities and deeper tissues of most animals and in man, sometimes harmlessly, sometimes causing diseases in their hosts.

One of the most abundant of the protozoa is that named **Amœba.** The largest amœbæ are just visible to the naked eye, although even these are too small to be identified except under the microscope. The smallest of them are not much larger than bacteria. They are to be found both in fresh and salt water, while some of them are internal parasites of other animals. But they are obtained most easily from mud or slime at the sides or at the bottom of water containing organic matter. In a greenhouse, where flower-pots are allowed to stand in saucers, the slime collecting in the saucers is a favourite habitat of *Amœba*. So also is the slime round the sides of tanks used either as marine or as fresh-water aquaria. When one wishes to find amœbæ

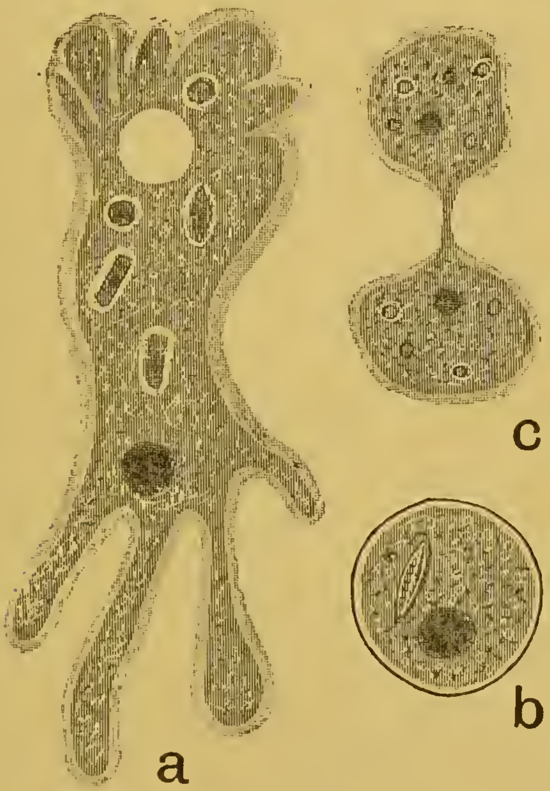

FIG. 9.—a. *Amœba proteus*, with retracted pseudopodia at one end near which is the contractile vacuole. At the other end are four protruded pseudopodia, and above them lies the nucleus. Embedded in the protoplasm are five food-vacuoles containing small ingested organisms. b. Encysted *amœba*. c. *Amœba* dividing by simple fission.

in ordinary ditch or pond-water, the water should be allowed to stand in a vessel until the mud has settled, and small quantities which can be removed by a pipette from the surface of the deposit of sediment should then be examined under the microscope. They are not to be found floating through the bulk of the water, for amœbæ are neither motionless, like the resting stages of *Protococcus*, nor do they swim actively through the water like its motile stages. They are creeping or flowing cells, which move slowly along some surface like the mud at the bottom of water or through thick slime. Even in the very small area of a drop of water between a glass slide and a cover-slip, they are usually motionless and inactive and difficult to see, until they have sunk to the surface of the slide or crawled out on the under surface of the cover-slip. They are also difficult to see (until the eye has become accustomed to their appearance) by reason of their transparency and absence of colour. They are simply little naked masses of protoplasm, without a limiting and defining cell-wall, and almost unceasingly changing their shape. It is by their movements that they first attract one's eye. *Amœba* has a thin external layer which is even more transparent than the central portion of the cell, which appears granular and contains various foreign bodies, such as pieces of food which have been taken in. The clear outer layer contains none of these. This difference in the protoplasm we express by saying that it has become differentiated into an outer clearer **ectoplasm** and an inner granular **endoplasm.** As one watches the *Amœba* one may see at some point in the animal the more central granular endoplasm suddenly flow out, pushing before it but not rupturing the external layer or ectoplasm, so that a long tongue or process called a **pseudopodium** protrudes from the surface of the animal. Sometimes several of these project from different parts, and none of them remain stationary for long. In some cases, it is the ectoplasm which first protrudes outwards to form the pseudopodium, the endoplasm then suddenly flowing into it. Thus the animal is constantly changing its shape. In this way, too, it creeps along ; for the whole of the protoplasm may follow in the direction of one pseudopodium, as has been already described in the case of the amœboid corpuscles of the frog (p. 5). The movements of free-living amœbæ, however, are much more rapid and lively than are those of amœboid cells. The pseudopodia may have different shapes. Sometimes, as is the case with the most common amœbæ of salt water, these are excessively long and slender, stretching out to a distance two or three times the width of the mass of the animal. In the most common fresh-water forms the pseudopodia are long but quite broad and have rounded ends. In others the pseudopodia may be short, blunt, or pointed. In the cases mentioned the pseudopodia appear upon any portion of the surface of the cell. In other cases very few processes, generally only two, are formed, and these appear at two definite points opposite each other, so that this kind of *Amœba* has an elongate, recognizable shape. It is not to be supposed that any specimen of *Amœba* may present all these different forms of pseudopodia. Careful observation will show that in most cases they conform to one of the types mentioned. As in all cells, there is a **nucleus** in *Amœba*, but in different animals it has different appearances. Usually it is a rounded oval, with small, regular, darker masses or **nucleoli** within it. Sometimes it is round ; sometimes there are a large number of small nuclei in place of one large nucleus.

Amœba is not the name of a single species or individual kind of animal. It is what is called the **generic** name of a number of different species which are all more closely allied to each other than to any other kind of animal. Thus, the dog, wolf, jackal, fox, and the cat, lion, tiger, and leopard all are different *species* of animals. But the dog, wolf, jackal, and fox are all closely allied and similar in structure, while the cat, lion, tiger, and leopard are similarly related. In order to distinguish the animals and express these relations what is called the **binomial nomenclature** was invented. Thus the generic name of the dog and its allies is *Canis*, and a second or specific name is added to distinguish the species to which the animal belongs. The dog is *Canis familiaris;* the wolf, *Canis lupus;* the jackal, *Canis aureus.* The generic name of the cat is *Felis.* The wild cat is *Felis catus.* The origin of the domestic cat is unknown ; it does not appear to be a cross breed. The lion is *Felis leo;* the tiger, *Felis tigris;* the leopard, *Felis pardus.* *Amœba* is a generic name and there are many species of *Amœba*, no doubt more difficult to distinguish because of the smaller number of visible characters, but still they are different animals, just as are the dog, fox, and wolf. To a certain extent these species of *Amœba* can be distinguished by the shape of the nucleus, the form and appearance of the pseudopodia, and to an expert eye by the general appearance of the whole animal. But beside the visible characters the species are separated by many others. Thus a species that is accustomed to live in fresh water is killed by being placed in the sea water in which a sea-water species is living. An amœba of salt or fresh water taken into the alimentary canal of man would almost certainly be killed and would certainly not set up the diseases caused by the species that may be found there. In certain cases two amœbæ of the same species coming together go through what is called **conjugation:** the protoplasms of the two fuse together and the two animals live as one for a time. If amœbæ of different species came together, either no result would follow or one would ingest the other.

By careful experiment, it has been found possible to accustom amœbæ to unusual conditions of life, to keep fresh-water species, for instance, in water to which salt has been gradually added. But we have no reason to suppose that experiment, however prolonged, could change a fresh-water species into one of the existing salt-water species. For it seems to be as true of the species of amœbæ as of the species of all animals, that species are kinds of animals with distinct structure, properties, and habits, and that it does not appear possible to turn one species into another existing species by the operation of external influences. They come as the result of inherent changes in their race, and having come they are either fit to live in fresh water or in salt water, or maybe, in some cases, even in both. But being fit to live in fresh water alone, they are perforce compelled, as it were, to adopt a fresh-water habitat. It is the species which chooses the fresh-water conditions and not the fresh-water environment which made the fresh-water species out of a salt-water member which had wandered from its race. The question of species, however, has to be very carefully considered. There is some reason to believe that undifferentiated, primitive organisms like *Amœba* are inherently more plastic to external conditions than are the more highly specialized Metazoa or multicellular animals. But this capacity of responding to changes in the environment is an innate quality, belonging to the organism itself, and is a congenital attribute of its race. This is shown by Dr. Dallinger's experiments with certain protozoa. During an interval of several years he exposed these protozoa to a very gradually increasing temperature. He began with 15·6° C. and ended with that of 70° C. But it must be observed that at each successive stage at which the temperature was raised, many individuals died off and only some survived. It is therefore clear that mere change in the environment does not produce internal changes in the organism favourable to its living under changed conditions. It appears, on the other hand, that in Nature there are living, even in the same species, individuals which are physiological variants, which possess inherent powers of response and adaptation not possessed by others. It is these which survive; it is the inherently unresponsive, the physiologically defective, which are eliminated by the new conditions enforced upon them. And what is true of physiological attributes is probably equally true of structural characters. Adaptation, be it structural or physiological, to any set of external conditions, is due to inherent and spontaneous qualities or characters of the race and not to direct environmental moulding.

For purposes of general study, the most convenient species is *Amœba proteus*, the largest found in fresh water. In this, the pseudopodia are long but wide, and are usually rounded or even expanded at their ends. The nucleus is not easily seen unless the specimen has been killed and stained, but even in a living state it may be recognized as a rounded oval structure embedded in the granular endoplasm, darker in appearance and of more even texture. It can move freely in the protoplasm and shifts its position during the creeping movements of the animal. A large contractile vacuole is always present, and its slow expansion and quick contraction can be studied with ease.

As *Amœba* moves about, it comes in contact with various little animals and plants living in the same mud or water. It may be observed **ingesting** these, taking them into its interior at any point. Sometimes two pseudopodia entrap the prey between them, and fusing together, embed it in the common mass of the animal. More usually the tip of a single pseudopodium flows round a particle of food, completely engulfing it, and subsequently carrying it back into the protoplasm of the cell-body. When the prey is part of the filament of an alga, like, for instance, *Spirogyra*, the *Amœba* engulfs a portion which remains attached to the rest of the plant. It is such small animals and plants that form the food of *Amœba*. The ingested prey may be seen to lie in the protoplasm surrounded by a small layer of fluid, which consists partly of water unavoidably taken in with the food, but which also contains some digestive juice similar in its action to gastric juice and secreted by the protoplasm. This little space containing digestive juice and food is known as a **food vacuole,** and several of them may be seen in one amœba. The living material of the ingested animal or plant is acted upon by the digestive juice, and its proteins are turned into soluble material. The digestion of the food can be watched best when it is a green plant. First the chlorophyll is destroyed and all the soft part of the plant disappears, leaving behind only the cellulose wall and a few particles of indigestible *débris*. The nutritive juice thus formed gradually passes out of the vacuole and gets lost to sight in the minute spaces of the protoplasm. It becomes, in other words,

assimilated, or built up into the living protoplasm. Finally, the indigestible remains are extruded at the nearest point.

Experiments show that *Amœba* requires either living protoplasm, in the form of the bodies of animals or plants, or dead protein matter, like minute particles of raw beef or white of egg, in order to live or grow. It cannot digest starch or fat, and, unlike a green plant, is unable to build up protein material from simple inorganic salts: nor, unlike the yeast plant, can it make use of ammonium tartrate as its nitrogenous supply. Like the yeast plant and green plants when sunlight is not acting upon their chlorophyll, it requires a supply of oxygen. Mineral substances, which appear simply to be those entering into the composition of protoplasm, it obtains partly from the protoplasm of the organisms it ingests and assimilates and partly from the small quantities of salts which are present even in fresh water. For its life-history, then, *Amœba* requires small quantities of mineral matter, protein, either in the form of living animals, which is the natural condition, or supplied it artificially, water, which it gets directly from its surroundings, and oxygen, which is dissolved in the water. The protoplasm or protein is digested and absorbed and the nutritive material passes into the ultra-microscopic interstices of the protoplasm. The indigestible portion is excreted or turned out. The real waste matter of the *Amœba*, that which comes from the actual wear and tear of its protoplasm in the processes of life, is secreted into the contractile vacuole and then discharged as an excretion from that, just as nitrogenous waste is removed from the blood by the kidneys of higher forms and discharged from the bladder to the exterior.

As a matter of observation it is not known how the carbonic acid, the result of the oxidizing process of the living protoplasm, is removed, but probably it is discharged into the water just as the oxygen is taken up from the water.

It is to be noticed that all these processes of taking in, building up, and giving out, go to make up what is called the vital activity of protoplasm. In the complicated bodies of higher animals mechanical conditions may come into operation. Thus, for instance, the absorption of oxygen by the lungs and the discharge of carbonic acid may be aided, in accordance with the laws of diffusion of gases, by the difference between the low pressure of oxygen in the venous blood and the higher pressure in the atmospheric air in the alveoli of the lungs ; while the excretion of carbonic acid may be aided by the fact that the blood in the lungs contains an abnormally large amount of that gas, while the air contains a very small amount. In such a condition of things the laws of diffusion of gases may come into operation. But in the case of *Amœba* there is no arrangement of this kind, and it is important to remember that it is one of the properties of the protoplasm of *Amœba*, and in all probability of all protoplasm, to absorb oxygen and discharge carbonic acid independently of pressure and diffusion. So also with the discharge of the nitrogenous waste matter. In the body of man the separation from the blood in the kidneys of urea and of water may be aided by the mechanical conditions of the complicated structure of the kidneys. But in *Amœba*, this secretion and discharge of waste matter goes on independently of specially adapted structures. It is one of the properties of the protoplasm of *Amœba*, and probably of all protoplasm, to remove nitrogenous waste matter.

When *Amœba* has an abundant supply of food, the building up of new protoplasm goes on more rapidly than the process of breaking down, and the *Amœba* grows larger. As is the case with all cells, there is a limit of size beyond which an *Amœba* does not go. Instead of growing larger, or of ceasing to feed, **reproduction** takes place. It cannot, however, be said that reproduction is simply the direct result of the attainment of a certain size. The size at which it takes place is different in the case of different species of *Amœba*, and even varies in the case of individuals of the same species. In the case of many single-celled animals, although not in the case of *Amœba*, it has been shown that although the most abundant supply of food be given, and the other conditions be favourable to active growth, reproduction by division will not go on for an indefinite number of generations. After a time the individuals appear to become more languid and feeble and the greater number of them die. A few, however, undergo the process of **conjugation**. In the case of *Spirogyra* it will be remembered that a kind of sexual reproduction takes place. The protoplasm of two cells united to form a spore. In the case of some Protozoa, after two cells have come together the nuclear matter and protoplasm of each fuse together, and the whole mass becomes enclosed in a firm cell-wall and breaks up into a set of spores. In other cases (*Paramœcium*, *infra*, p. 69) after the two cells come together in the process of conjugation, a complicated interchange of nuclear matter and apparently of protoplasm goes on between the two, and ultimately the two separate again, and each takes up the usual method of reproduction by simple division. In *Amœba* the process of conjugation has been noticed, but the exact details of what occurs are not known. It is, however, clear that although reproduction by division is due in the first place to growth, this process will not occur to an indefinite extent in any individual case; reproduction is not a simple effect of overgrowth. As in the case of excretion and respiration, we have to fall back on the statement that, as an observed fact, it is an innate property of the mass of protoplasm known as a cell to divide.

The actual process of reproduction in *Amœba* begins with the nucleus. This becomes elongated; a contraction appears in the middle, giving it a dumb-bell shape; the contraction deepens until the elongated nucleus is separated into two nuclei. During the division of the nucleus the surrounding protoplasm also constricts, and ultimately the whole animal divides in two (Fig. 9, *c*). In this process there is no trace of any distinction between the two halves of the daughter amœbæ. Both are exactly alike, and, except in size until they have grown, they are exactly like the parent cell.

One notable point in which the reproduction of Protozoa by simple division differs from the reproduction of higher animals must be noticed. A man, or a cat, or dog gives rise to sons and daughters and ultimately dies. In the cases of

Amœba, the sons and daughters are themselves the body of the parent ; the single *Amœba* as an individual disappears. As a mass of protoplasm it is not subject to death except as an accident. Death plays no part as a naturally recurring event in the life of *Amœba*. In that sense it is immortal, since its individuality becomes merged in each successive generation in that of its offspring. As we know only of reproduction by simple division in the case of *Amœba* and of many other Protozoa, those alive just now have therefore descended, so far as we can infer, in a direct continuous chain of division from the first *Amœbæ* that ever lived.

There is one other occurrence in the life of *Amœba* which must be noticed. Occasionally, especially under unfavourable conditions, a thin skin or cell-wall forms round the *Amœba*. This is excreted by the protoplasm and is a substance of a chitinous nature. The pseudopodia are withdrawn, the animal assumes a spherical shape, and the cell-wall, or **cyst**, becomes thick and nearly opaque (Fig. 9, *b*). After a period of quiescence the wall of the cyst ruptures, and the *Amœba* creeps out, leaving behind it the empty cyst. Except that it may serve as a means of protection against untoward influences, the meaning of this process of encystment is not known. Such resting cysts are called **hypnocysts**.

CHAPTER IX

CILIATED PROTOZOA

VORTICELLA (THE BELL ANIMALCULE)

IN many Protozoa allied to Amœba the cell processes corresponding to the pseudopodia assume peculiar shapes. A single, long, tapering process which is vibratile but cannot be withdrawn resembles very closely the two long cilia or flagella to be found in the motile stages of *Protococcus.* Sometimes the processes are branched at the tips. In others the tips are expanded into tiny knobs, which under the microscope give the appearance of minute pins inserted into the cell by their points, as is shown in Fig. 10. An occurrence of very great interest may be seen in a protozoon with tentacle-like pseudopodia by any one who cares to watch sufficiently long for it. The Protozoon in question is an acinetan called *Sphærophrya* (Fig. 10). It is very common in fresh-water ponds all over this country, and it may be found if the method recommended on page 7 be followed. It is a small form, nearly circular, and possessing a large number of very long slender filaments with knobs at their tips. These knobs consist of semi-liquid tenacious protoplasm, probably with poisonous properties. By them small swimming Protozoa are captured, and in a captured animal, after a short struggle, the movements of life become paralysed, and, by the bending of the knobbed filaments the prey is gradually pulled into the cell-body and there engulfed. Here, then, is a case where, instead of a simple pseudopodium which may disappear and be reformed at any moment, there is a more elaborate structure specialized for a particular purpose.

Sphærophrya sometimes divides by simple transverse fission. In Fig. 10, *a*, this has occurred, and the two daughter cells are beginning to draw apart. The only difference to be noticed between the two is that one is rather smaller. In Fig. 10, *b*, which was drawn from the specimens about fifteen minutes after Fig. 10, *a*, the smaller result of the division shows a more irregular shape, and its knobbed filaments, at first of equal length to those of the larger animal, have become much shorter. At Fig. 10, *c*, drawn a few minutes later, the smaller organism has become much more elongated and nearly oval ; and a large and active contractile vacuole appears in it. Suddenly, as one watches it under the microscope, a most remarkable change occurs. The knobbed tentacles at one end of the oval break down into a faint transparent layer of protoplasm, as shown in Fig. 10, *d*, and almost as suddenly this layer of protoplasm breaks up into a number of delicate short waving lines of protoplasm. These are called **cilia**, little hairs, and by their rapid vibrations the oval animal, hitherto stationary, is propelled through the water at a pace which makes it difficult to keep it in the field of the microscope (Fig. 10, *e*). After a short period of vagrant life the animal settles down ; the cilia again disappear and knobbed filaments take their place, while the nearly spherical form is assumed again. Cilia, then, in their simplest condition are protoplasmic filaments and may be regarded as specialized pseudopodia.

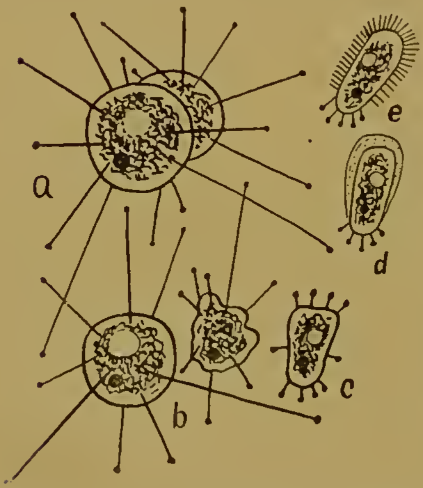

Fig. 10.—An Acinctan dividing. a. The two daughter cells are alike ; b, one cell becomes irregular in shape and the suckers are shorter ; c, the cell is elongating ; d, the suckers, except at one end, have broken down into a zone of protoplasm ; e, this zone has broken up into cilia, and the animal begins to swim.

A large number of the most common Protozoa are characterized, among other features, by the possession of cilia. These have two chief uses : they may serve to propel the animal through the water, or, when the animal remains stationary, their vibrations may draw currents of water towards the animal itself, and in these currents are carried the small organisms which serve as food. Another feature in the ciliated Protozoa is that their protoplasm instead of being naked, as in *Amœba*, is protected by a delicate cell-wall called a cuticle. This, like the cyst of *Amœba*, is a chitinous material secreted by the protoplasm. A great advance in complexity of structure results. *Amœba* and other naked Protozoa can take in food at any point of their surfaces. In the other forms, the cuticle either prevents this or makes it difficult. And so in the ciliated Protozoa a small part of the surface is usually unprotected by cuticle and serves as a **mouth** to take in food and an **anal spot** at which excreta are discharged. This soft part of the surface of the animal, no doubt for reasons of safety, is frequently sunk down until it comes to lie at the bottom of a funnel-like depression which may be called the **pharynx** or **gullet.** Round about this, special bands of cilia serve to sweep currents in towards the mouth, and the whole depression may be covered and protected by a movable part of the body of the animal which serves as a flap or lid to the pharynx. It is to be remembered that all this structure is within a single cell. The parts are not formed by the arrangement of many cells, like the mouth, gullet, and so forth, of higher organisms. Organization, the formation of organs, although most familiar to us in the case of many-celled animals, exists in single-celled animals also. The capacity of becoming organized, then, is one of the innate properties of protoplasm.

Among common ciliated Protozoa are the bell animalcules of the genus *Vorticella* and the slipper animalcules of the genus *Paramœcium*. The various species of *Vorticella* are to be found almost everywhere, in fresh water or in sea water. They are small in size, but under the microscope they may be recognized at once by their habits and shape. Each consists of an oval or bell-shaped head attached to water-weed or pieces of stone, or even to the shells or bodies of small aquatic animals. The whole animal, which, although very complicated, is a single cell, is clad with a delicate cell-membrane or cuticle. At what may be called the lower or attached end of this, the cuticle is drawn out into a long, exceedingly delicate, hollow stalk, by the extreme end of which it is anchored. Within this hollow stalk a darker protoplasmic thread runs from the protoplasm of the cell-body in a very loosely twisted spiral to the extreme end of the stalk. Under the higher powers of the microscope this axial thread of protoplasm is seen to be granular, and the granules are arranged in lines across the short diameter of the thread, giving it a striated appearance. The slightest jar causes the stalk to contract, and the contraction consists in the loose spiral of the thread of protoplasm suddenly coiling into a very tightly rolled spiral, so that the stalk is shortened into a thick coiled cylinder not so long as the bell-shaped head, which is pulled down close to the point of support. The contraction is due, not to a change in the actual bulk of the protoplasm, but to a change in shape. So also in the muscles of higher animals the shortening of a muscle fibre is always accompanied by a change proportionate to the increase in the thickness of the fibre. The unrolling of the spiral, and the consequent protrusion of the *Vorticella* from its place of anchoring, takes place much more slowly.

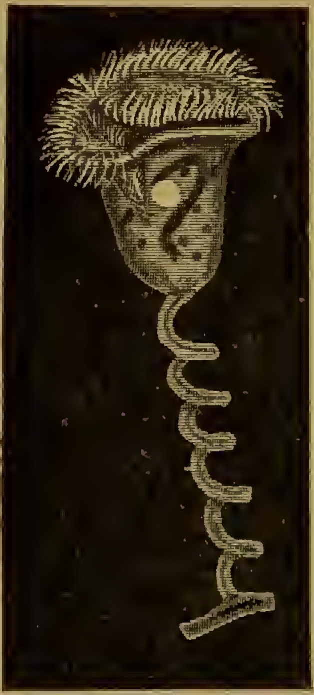

FIG. 11.—Living Vorticella in the act of expanding; the spiral stalk with central contractile thread is uncoiling; the peristome has expanded and the cilia are in active motion; under the raised edge of the disc a ciliated pharynx passes into the interior of the cell; to the right of the pharynx the pulsating vacuole is seen as a clear spot; looped in the protoplasm is the horse-shoe-shaped nucleus; several food-vacuoles appear as dark spots.

In the contracted condition the head, or cell-body, of *Vorticella* is nearly globular. As the uncoiling proceeds, the globe slowly becomes bell-shaped. The circular edge of the bell mouth, which has been tucked into the bell cavity, first expands, and is seen to form a circular lip, of which the edge all round is slightly folded back. This is called the **peristome,** because it surrounds the **stoma,** or mouth. As the peristome expands, the edge of a circular disc lying in the mouth of the bell is pushed up, like the lid of a "Jack-in-the-box," and from between the pushed-up edge and the inner edge of the peristome one or two long, stout bristles are protruded. At the same time a circle of long cilia which are arranged around the edge of the disc begin to vibrate very rapidly and to cause a whirlpool in the water, by which any small floating objects are drawn inwards to the opening under the edge of the disc. This opening leads into a funnel-shaped depression, the **pharynx,** lined with vibratile cilia, and leading inwards to the centre of the cell. At the bottom of this depression a small area, not covered by cuticle, serves as the actual mouth by which food particles drawn into the pharynx by the action of the cilia are actually taken into the protoplasm. Another soft area at the side of the funnel serves as the anus by which the indigestible portions of the food are extruded. In the protoplasm near the anus is a large **contractile vacuole,** which one may see slowly expanding and rapidly discharging its contents into the pharynx, from which they escape to the exterior. In the protoplasm, also, many **food vacuoles,** like those of *Amœba*, may be seen at different places. Lastly, the **nucleus** can be seen as a very long and rather narrow granular mass, twisted into a horse-shoe shape.

Notwithstanding the much greater complexity of this unicellular animal the processes of respiration, digestion, and excretion take place precisely as in *Amœba*. As it is fixed to a particular spot, and so can be kept under observation more easily, it is more easy to experiment with. If granules of carmine be placed in the water near it, the direction of the ciliary currents may be observed, and the precise spot at which the food material is taken into the protoplasm may be noted. It is possible also to study the motion of the cilia in detail. By the introduction into the water on the slide of a minute trace of dilute iodine—or better, of a drop of water into which tobacco smoke has been blown through a tube—the movements of the cilia may be made slower, although a slight overdose permanently arrests them. If a single cilium be watched, the movement may be seen to consist of a series of quick bendings in one direction, each bending being followed by slower recovery of the straight position. The cilia are themselves protoplasmic structures, and the bending and recovery are due to alternate contractions of the protoplasm on either side of the cilium. Ciliary motion, then, is a form of protoplasmic activity, and is an innate quality of some forms of protoplasm.

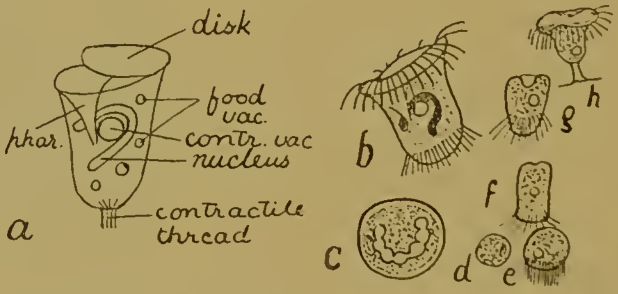

FIG. 12.—**a.** Diagram of *Vorticella*. **b.** Motile form. **c.** Encysted *Vorticella* with beaded nucleus. **d.** One of the spores into which **c** divides. **e** to **h.** Stages in the development of spore into adult form.

Reproduction in *Vorticella* is more complicated than in *Amœba*. First, reproduction by longitudinal fission occurs. The nucleus divides as in *Amœba*, and then division of the cell-body occurs. At first the two daughter cells remain attached to a common stalk, and in many close allies of *Vorticella*, "colonial forms," with a number of heads on the same stalk, may thus be formed. But in *Vorticella*, one part remains attached to the stalk, the other half grows barrel-shaped, and towards the lower end of the barrel a second ring of cilia develops (Fig. 12, *b*). Then the barrel-shaped *Vorticella* leaves the parent stalk, and, propelled by the ring of cilia, swims about actively for a time. Ultimately it settles down, and a stalk grows out by which it is anchored in a new locality, and it becomes indistinguishable from the parent organism or from its stationary twin. In this way the fixed *Vorticella* may spread from place to place, and those animals that settle down in positions favourable for food survive. Occasionally, however, it may be seen that a fixed form gives rise directly to the vagrant form by developing a posterior ring of cilia and breaking away from its stalk. This happens in circumstances where the water is evaporating, as, for instance, when a number of *Vorticella* are kept for a few hours under observation in a very small quantity of water.

In a second form of reproduction the *Vorticella* divides into a large and a small portion, the latter part appearing simply like a bud upon the larger. The small cell becomes an elongate, barrel-shaped, vagrant form, with a posterior ring of cilia, as in the case first mentioned, the only difference in appearance being that the vagrant buds are very small. Sometimes the *Vorticella* divides in two, and while one half remains attached to the stalk the other breaks up into several vagrant forms. Thus, when this kind of division has been occurring, there results a number of fixed forms and a number of small wandering forms. Between these conjugation may occur. A vagrant form comes up to one of the fixed forms to which it has wandered, and the protoplasm of the two completely fuses, the small vagrant forms being entirely absorbed in the fixed form. After the process, reproduction by fission occurs more vigorously in the fixed form. The interest of this process of conjugation is that it foreshadows the sexual reproduction of higher animals. The large fixed form represents the egg-cell of the female, which is usually large and stationary; while the small, actively swimming form corresponds to the spermatozoon, which is a small, freely moving cell that seeks out and fuses with the egg-cell.

A third method of reproduction is preceded by encystment. A *Vorticella* becomes detached from its stalk, and secretes a thick cuticle (Fig. 12, *c*). Within this the nucleus and the protoplasm break up into a number of little spores, in each of which there is a portion of the nucleus and some protoplasm. A cuticle forms around each spore, and ultimately the cyst ruptures, liberating the spores. It is by these that *Vorticella* most easily gets carried from place to place, by the wind or by other agencies. The thick wall of the spore protects it against untoward influences. When the spore reaches a place favourable to development, its cuticle ruptures and the protoplasm creeps out as a little naked, partly amœboid, mass of protoplasm. This rapidly becomes elongated, and develops a ring of cilia (Fig. 12, *d* to *h*). It swims about actively, and finally settles down as the adult form, with stalk, pharynx, peristome, disc, and so forth. This foreshadows another feature of the reproduction of higher animals. The first stage in the life of the young of a worm, or a frog, or a man is very unlike the adult stage. It is a simple single cell, which only after a long and complicated series of changes becomes like the adult. Sometimes, as in man, all these changes go on within the body of the mother; sometimes, as in the frog, some of the stages swim actively about as tadpoles, get their own food, and live exactly as complete animals while they are finishing their development. But in the cases of higher animals the building up of the adult form takes place by the multiplication of cells. The animal begins as a single cell: the adult is formed almost of innumerable cells. In the case of *Vorticella* the adult animal and each stage in its growth is to be regarded as a single cell. The development of the animal consists in the organization and specialization of its protoplasm.

CHAPTER X

CILIATED PROTOZOA (*continued*)

PARAMŒCIUM (THE SLIPPER ANIMALCULE)

PARAMŒCIUM is one of a class of Protozoa called **Infusoria.** The individuals of this class are readily obtained in infusions of organic matter, and more particularly in those made from hay, grass, or flowers steeped in water. Infusorians can thus be readily obtained. They are widely distributed on plant surfaces encysted in resting cysts; these cysts are technically called **Hypnocysts,** to distinguish them from reproductive cysts, which are known under various names. The hypnocysts are microscopic sacs of a spherical form, composed of a substance allied to chitin and of a resistant nature. Within them the protoplasm of the individual is enclosed and is protected against desiccation and other harmful influences. Thus invested, the organism exists in a relatively passive condition. The cysts are blown from place to place by the wind, and since they are extremely small, they readily adhere to the surface of plants, hay, and grass. When any of these are placed in water the cyst is dissolved by the organism within, which comes forth, to feed, grow, and reproduce. Its reproduction is very rapid in suitable solutions, namely, water containing putrefying matter or minute particles of vegetable *débris*. In a very short time, therefore, the water in which almost any vegetable matter has been steeped will be swarming with Paramœcia and other Infusoria.

Paramœcium is a relatively large Protozoan (Plate I). It can be readily seen with the naked eye as a white speck. It measures in its longer axis about $\frac{1}{5}$ to $\frac{1}{4}$ millimetre.

Unlike *Amœba*, its form is constant and it may be compared to that of a slipper. Its constancy of form is due to its investment by a firm **cortex** or **ectoplasm** (ec), and an outermost **cuticle** (cu). Within the cortex is a much more fluid protoplasm, constituting the **medulla** or **endoplasm** (en). Under the higher powers of the microscope this medullary protoplasm is seen to have a reticulated or network structure. The net is composed of a denser protoplasm, called the spongioplasm, and the meshes are filled with a more fluid and clearer protoplasm, the hyaloplasm. The cortex presents a similar reticulated appearance, but the network is much closer and firmer.

The organs of locomotion in *Paramœcium* are not pseudopodia as in *Amœba*, but cilia (c). These are extremely fine constantly vibrating processes of the cortical protoplasm; they pass through minute pores in the cuticle to the exterior. The whole surface of the body is covered with them, and they are disposed in regular lines running along the length of the body. *Paramœcium* moves with its anterior or broad end forwards and its ventral or "gullet" side downwards.

On this ventral or under-surface (Plate I) there is a depression lying towards the broader anterior end, and this leads backwards into a tubular part, which extends into the medulla. The depression is called the buccal depression and the tubular part the œsophagus or pharynx. This latter is traversed along its length, on its dorsal side, by a thin velum or protoplasmic membrane, which is in continual undulation. Its movements, together with those of the cilia which line the pharynx, probably serve to set up currents in which food particles are wafted into the pharynx. They are then driven to the bottom of this, where, as they accumulate, a bleb or rounded mass of food-matter is formed. This food material is enclosed in a vacuole of water, and when the whole mass has reached a certain size it becomes jerked off from the pharynx and is carried into the medulla. The mechanism of this "jerking off" from the pharynx is apparently of a simple mechanical nature. The medullary protoplasm is rotating at a constant rate, round and round, inside the cortical layer. The cohesion of the tiny ball of food material to the pharynx is only weak, and consequently, as it gets bigger, the friction of the moving medullary protoplasm becomes greater, until at last the resistance offered to it by the little ball of food matter is sufficiently great to carry it away from the pharynx. It then travels round with the medullary current.

While contained in these travelling vacuoles (d.v), the food material is gradually digested by a digestive fluid secreted by the protoplasm, in which the vacuoles lie. After these have completed one or two rotations, most of the soluble part of the contained food is digested and only insoluble *débris* remains. This is then carried by the vacuoles towards a spot (v.e) just behind the buccal depression, and here it is ejected to the exterior. The point at which this egestion continually occurs is called the "anal spot," and the vacuole which opens to the exterior is known as a **vacuole of egestion.**

Towards either end of the medulla there is situated a **pulsating** or **contractile vacuole** (c.v). They are very similar to those in *Amœba*, but in *Paramœcium* they are constant in position, continually reappearing in the same spot. Each one commences as a minute drop of fluid in the medulla, and presently from six to ten rays appear around it; these soon become bigger and longer, and ultimately open into the central drop, which has also been getting larger. Suddenly they flow together and then the fluid content is discharged through minute canals to the exterior. The fluid content is nitrogenous in nature and appears to be allied to the guanin excreted by the kidneys of birds. The pulsating vacuoles appear therefore to be the excretory organs of *Paramœcium.*

Respiration takes place over the whole surface of the body, CO_2 diffusing out to the surrounding water and oxygen passing inwards.

Lying in the middle of the medulla is a large oval nucleus, (mg), which is peculiar in that it stains uniformly and does not show the existence of any chromatin grains or network. Situated quite near it there is in some species one smaller nucleus, and in other species two smaller nuclei (mi), usually situated one at either end of the larger one. These exhibit a grain of concentrated chromatin when they are stained. The larger nucleus is called the **meganucleus** and the smaller ones the **micronuclei.**

During ordinary trophic (vegetative or nutritive) existence, the micronuclei are small and the chromatin concentrated into a single granule. But, as we shall later see, when sexual reproduction is taking place, they become larger and their chromatin becomes more apparent.

REPRODUCTION

In *Paramœcium* reproduction may be either asexual or sexual.

In asexual reproduction the organism constricts across the middle of its length and the two individuals thus formed swim away (Plate I, left-hand figure). The process, however, is not a simple one of mere fission in the sense implied that we have simply cut some body into two. The details of the process appear to be as follows : a second mouth (g) first makes its appearance and then each of the two contractile vacuoles (c.v) apparently divides into two. Around the new mouth new cilia are developed. The cortex then constricts in about the middle of the organism and forms a furrow encompassing it. At about the same time, the micronuclei (mc) are seen to enlarge and to elongate, and the characteristic appearances of a mitosis (nuclear division) become visible. The meganucleus (mg) then elongates, becomes constricted in the middle, and presents a longitudinally fibrillated appearance. The process of actual division then begins ; it proceeds in the following order : division of the micronuclei into two, followed by that of the meganucleus, and subsequently that of the protoplasm of the cell itself.

SEXUAL REPRODUCTION

Conjugation

There are several species of *Paramœcium*, and in some there are two micronuclei, while in others there is only one. The process of sexual reproduction is a little simpler in those species with a single micronucleus, and we shall therefore consider the mode of reproduction in such a species.

The first stage is the temporary association of two individuals which become applied by their ventral surfaces (Plate I, Fig. 1). The meganucleus (mg) at first undergoes no change (Plate I, Fig. 1). The micronucleus in each individual divides into two (Fig. 2). One of the two then becomes absorbed, and the remaining one begins to lengthen and divide (Fig. 3, 2nd). The division becomes completed, and there are now two micronuclei in each organism (Fig. 4). Of these one remains stationary, and may be called the female pronucleus (Fig. 5, f), while the other (m) in each individual migrates over into the protoplasm of its fellow conjugant.[1] The migratory nuclei (m) may be called the male pronuclei. The position reached is this: There are two associated organisms. In each individual is a female pronucleus, that arose within itself, and a male pronucleus, which it received from its fellow conjugant. At about this period the two individuals separate (Fig. 6), and the male and female pronuclei now fuse to form a single cleavage nucleus (Fig. 7). This then begins to lengthen and subsequently divides into two. The two divide again (Fig. 8), so that in both conjugants there are four nuclei. Two of these begin to enlarge, and ultimately they form the new meganucleus (Fig. 8, mg), while the remaining two become the new micronuclei (mi). Each conjugant thus contains two meganuclei and two micronuclei. At about this stage, a longitudinal plane of division appears in each of the conjugants, which passes down and divides the four nuclei into two sets (Fig. 8); each set contains both a meganucleus and a micronucleus. Along this plane fission into two individuals occurs, resulting therefore in the multiplication of the original two conjugating individuals into four.

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[1] The term "conjugant" means a conjugating individual.

In some cases the cleavage nucleus (Fig. 7) may divide more than twice, and there will then result more than four individuals.

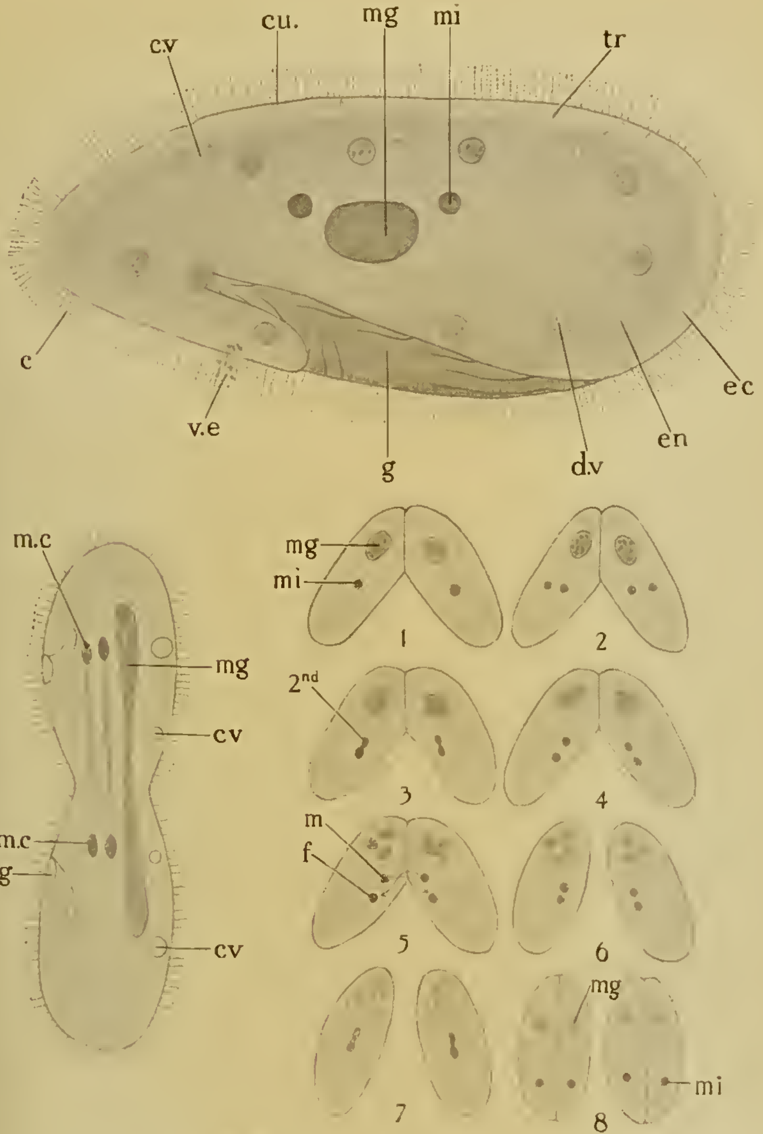
While these changes of the micronuclei are going on, the meganucleus becomes first tuberculated (Fig. 4), and then breaks up into particles (Figs. 5 and 6). Ultimately they are absorbed by the cell protoplasm, and possibly may be utilized as food material to supply the energy involved in the nuclear divisions and growth.

A survey of the facts thus shows us two things in relation to sexual reproduction in this organism. First, it is apparently not the protoplasms of the two cells which coalesce and mingle ; it is quite clearly not the two individuals themselves which conjugate or fuse. The actual conjugating bodies are the micronuclear elements, the male and female pronuclei. This fact points to the conclusion that it is the nuclear elements which hereditarily transmit the qualities of a race, rather than the cell protoplasm. There are, however, some observations which render it possible to believe that in some exceptional cases the protoplasm of the cell may play this part. But the rule is otherwise. In *Spirogyra* (p. 43) and in *Monocystis* (p. 82) we have a conjugation where not only do the nuclei fuse, but the protoplasm of the cell does so too.

In the second place, we cannot distinguish morphologically between the two conjugating nuclei formed in each individual. In staining capacities, in size and in form, they are practically identical. The only distinction we can make is of a physiological kind, one migrates and the other does not.

But the point we wish to emphasize is this : that in these cases (*Paramœcium*, *Monocystis*, *Spirogyra*, &c.) there is no morphological differentiation into male and female sex-cells, differing markedly from each other. A sexual reproduction, where the two uniting sex-cells (gametes) are similar or identical in morphological characters, is spoken of as **conjugation.**

PLATE I



Top figure. Ventral or under view of Paramœcium. Left-hand figure. Paramœcium multiplying by transverse fission. Figs. 1–8. Different phases in conjugation. Fig. 1. Two conjugants associated. Fig. 2. Micronucleus divided into two. Fig. 3. One of the two resulting nuclei has disappeared (represented by faint circle) and the other (2nd) is dividing again. Fig. 4. Division of 2nd nucleus completed, with the production of a male and female pronucleus. Fig. 5. Male pronucleus in each conjugant is about to migrate over to the other conjugant. Fig. 6. Migration completed and separation of the two conjugants. Fig. 7. Fusion of the male and female pronuclei to form segmentation nucleus Fig. 8. Segmentation nucleus divides into two, one becoming a new meganucleus and the other the new micronucleus. Each conjugant divides longitudinally. **c**, cilia; **cu**, cuticle; **c.v**, contractile (pulsating) vacuole; **d.v**, digestive vacuole; **ec**, ectosarc (ectoplasm); **en**, endosarc (endoplasm); **f**, female pronucleus; **g**, "gullet" (buccal depression), **œ**, œsophagus" ("pharynx"); **m**, male pronucleus; **m.c**, micronucleus; **mg**, meganucleus; **mi**, micronucleus; **tr**, trichocysts; **v.e**, vacuole of egestion, discharging insoluble food-substance.

Two features in the processes of reproduction in *Paramœcium* are worthy of notice. The first is that the new meganucleus is not derived from the old one, but is a direct product of micronuclear bodies. The second is the apparent futility and waste of energy involved in the disappearance of one of the two micronuclei which result from the first division (Fig. 3), since the remaining one (Fig. 3, 2nd) has to divide again in order to produce two nuclei (Fig. 4), thus simply restoring the condition seen in Fig. 2. Some sort of explanation of this curious phenomenon may be reached, in light of modern knowledge, by the following considerations :—

Individuals of *Paramœcia* are not only vegetative individuals (zygotes), but they are also sex-cells (gametes). We have no reason to believe that all individuals of *Paramœcia* are identical. Their size, ratio of length and breadth, activity, powers of resistance, and other qualities are very probably different in different individuals. If this is so, then when two individuals conjugate and part of the micronuclear elements of both is exchanged with subsequent fusion with another part of the micronuclear element which remains in each individual, it follows that each such conjugant is carrying two sets of alternative qualities. There are those which belong as it were to itself, and there are those derived from its fellow conjugant. The hereditary factors which represent each of these two sets of qualities may be carried in the single micronucleus of each individual. If this process were to go on indefinitely, the micronuclei of the *Paramœcia* of to-day would be carrying the hereditary factors of all the qualities of their remote ancestry, extending back perhaps to millions of years. This gives us a complexity of organization of the micronuclei which is quite inconceivable, and is not in accord with analogous facts in other realms of the animal kingdom. But if we cannot postulate this very complicated hereditary mechanism, then we are driven to postulate the alternative condition, namely, that at some point in the life-history of each individual some of the ancestral characters are thrown out of the micronuclei, There are reasons which justify us in believing that this segregation of alternative ancestral qualities (namely, shortness *versus* length, capacity for greater speed *versus* capacity for slower speed, and so on) may occur at this first division of the micronuclei (Fig. 2).[1] The nucleus which disappears carries, let us assume, the factors which determine shortness, and the one which remains those which determine length, or *vice versâ.* It consequently follows that, if this postulate be true, we may have three conditions of hereditary transmission arising from the conjugation of two *Paramœcia.* For the nuclear contents of some *Paramœcia* may be carrying the factors of shortness and those of others the factors of length. Hence when two conjugants meet we may have the following possible matings :—

Shortness × Shortness = pure for shortness.
Length × Shortness = hybrid.
Length × Length = pure for length.

Such a postulate, at any rate, affords a rational explanation for a phenomenon which is otherwise quite meaningless. Moreover, such segregation of ancestral characters has been experimentally demonstrated in higher forms. It is then known as Mendelism or Mendelian segregation.

Regarding *Paramœcium* from another standpoint, several other features of interest are observable. These involve the relationship and nature of the two kinds of nuclei which are present. In *Amœba*, as we have seen, only one kind of nucleus exists. In endeavouring to fathom the meaning of the double nuclear content in *Paramœcium*, we have to bear in mind the suggestive fact that during the trophic or vegetative stage of existence the meganucleus is large, while the micronuclei are small. On the other hand, as soon as the trophic phase becomes no longer the dominant one, but is as it were overshadowed by the sexual phase, then the meganucleus breaks up and disappears, ostensibly supplying nourishment for the conjugating individuals at the time when feeding in the usual way is not possible. And it is at this time that the micronuclei enlarge and assume a state of marked activity. Clearly, then, these facts suggest that the meganucleus corresponds to the nuclei of the somatic (body) or vegetative cells of the Metazoa, while the micronuclei represent the nuclei of their germinal (gametic) cells.

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[1] The student should compare this phenomenon with the formation of the first polar body or first reduction division in the maturation of the germ cells of the Metazoa (p. 324).

If this is so, we can no longer regard *Paramœcium* as a unicellular organism, for clearly its nuclei afford an indication that its body is constituted by at least two types of cells. But, of course, it is all a matter of definition. If we regard a single cell as being constituted by a single mass of protoplasm enclosing one or several nuclei, then *Paramœcium* may be thought of as a single cell. But the logical extension of such an idea leads us into some difficulties, for then we must regard the syncytial, striped, multinucleated muscle fibre of a Vertebrate as a single cell. And the development of the muscle fibre shows that such a conception of it is not justified.

A further feature of interest arises when we put the question : Why is the new meganucleus derived from the micronuclear elements instead of from the old meganucleus? The answer may be found in the general biological necessity that some unit must serve as the hereditary carrier of all the qualities of the race. With but few doubtful exceptions, everything points to the conclusion that it is the germinal nucleus which plays the part of this unit. We have just seen reason to regard the micronuclei as the representatives of the germinal nuclei of higher forms. Granting this, then the micronuclei of *Paramœcium* will be carrying all the factors that determine the hereditary qualities of its race. Now among such qualities, those that determine the possibility of nourishment—that is, the metabolic processes—its extent, its rate, its nature, and so on, rank as very important ones. But we have seen evidence to show that it is not the micronuclei but the meganucleus which controls the general metabolism of the organism. If this is so, then this body—the meganucleus—since it is derived from the micronuclei which do not control the vegetable or nutritive processes, may be looked upon as a segregation from them of those total factors which are concerned in determining the general metabolism of the individual. Thus again an appeal to the conceptions turning around the phenomena of segregation enables us to explain what in some respects appears to be a paradoxical or inexplicable condition of affairs.

CHAPTER XI

THE SPOROZOA, OR THE PARASITIC PROTOZOA

MONOCYSTIS

THE parasitic Protozoa are forms which do not live an independent and free existence, but derive their nutriment from the hosts which they infest. They are of very wide distribution, and there is probably no class or order of the Metazoa free from their presence. They infest both the external tissues and internal organs of their hosts. Some live throughout almost their whole existence as intracellular parasites within epithelial or blood-cells, while others pass part of their life in some cavity of the host, such as the gut, blood-spaces, or cœlom.

Their effects upon the host vary widely. As a rule the host appears to be unaffected by their presence. Host and parasite seem to have attained a position of stability: the host does not poison the parasite and the parasite does not injure the host. It is a mutual accommodation which has been brought about by the elimination of hosts which were too susceptible to parasites and of parasites which were not immune to the influences of the host. We have to bear in mind that the adjustment of a parasite to its host is one of the greatest conceivable nicety, and a slight disturbance of the even balance results in the destruction of either the one or the other. It is probably due to this fact that we owe the disappearance of malarial fever in this country. The balance between the English *Anopheles* gnat and the malarial fever sporozoan was disturbed and the parasite could no longer live successfully in the stomach of the gnat. Possibly some chemical mutation occurred in the juices of the stomach of the English *Anopheles*, which rendered it impossible for that particular phase in the life of the malarial parasite which normally played its part there to any longer maintain itself.

But though, as a rule, parasite and host are in even balances, there are cases where the advantage lies with the parasite, and disease or death with the host. Europeans visiting malarial districts in the Tropics for the first time are very prone to suffer more or less severely from malaria. And even lower forms of life may succumb to the attacks of protozoal infection.

Parasites are biologically regarded as degenerate forms. They differ from the free living members of their class in very definite ways. A comparison of the parasitic *Monocystis* with the free living Protozoa we have already studied brings out these differences quite clearly. *Amœba* and *Paramœcium* both ingest their food in the form of solid particles. *Monocystis*, which lives the greater part of its life cycle in the seminal vesicle of earthworms, absorbs its nutriment in a liquid form from the juices of its host. This absorption takes place over the whole surface of the parasite's body, doubtless largely by osmotic processes. There are thus no special digestive organs ; gullets, pseudopodia, and digestive vacuoles are all absent. Again, the excretion of waste matter proceeds over the whole surface of *Monocystis* : there are no contractile vacuoles as in *Amœba* and *Paramœcium*. Neither does *Monocystis* possess any definite organs of locomotion. In *Amœba* there are pseudopodia, and in *Paramœcium* there are cilia. A limited sort of movement is possessed by the parasite at a certain phase in its life cycle, but organs of locomotion are altogether absent. While, however, in its vegetative organs a protozoan parasite manifests degeneration, we shall find that its reproductive processes are highly elaborated. The end attained by this elaboration is a greatly increased power of rapid and extensive multiplication.

Monocystis cannot live indefinitely in a single earthworm ; sooner or later the worm will die, or its parasite will have multiplied to such an extent that the food supplies available in the host will not sufficiently avail for the sustenance of the parasite. Then it must pass to another host. But it is at this stage that the dangers of destruction loom large for the parasite. *Monocystis* is not so constituted at the stage when it passes from one host to another that it can spontaneously migrate in search of a new host, for it now exists as spores, which are quite passive and are encysted in a closed cyst. The probabilities of these reaching another host are remote. But unless they can do so the race will cease to exist. The dangers of destruction at this stage of the parasite's existence are reduced by the enormous number of spores which are produced. "Many are called but few are chosen." Of the hundred thousands produced but few ever reach a second host-worm. But they are enough to perpetuate and maintain the race in time and space.

The destruction of potential individuals is enormous. At first sight it may appear that here, perhaps, it is not wholly a question of "fit" or "unfit," because among the destroyed may be the "fittest" and among the "chosen" may be the unfittest. Doubtless there is some truth in this. Chance to a great extent determines which among many thousand cysts shall be swallowed by a worm not yet infested. But time brings all things; and the individuals which possess the most protective cysts and the most resistant spores will, in the long run, survive as the procreators of their race. The spores which can survive the longest have increased chances of being swallowed by a worm, and the passive struggle in which survival or elimination is determined may be waged in the fleeting interval of one short hour, more or less.

Monocystis belongs to an Order of the Sporozoa called the **Gregarinida.** This Order is characterized by the structural complexity which its individuals manifest. But *Monocystis* is one of the simple forms among the Order. The life cycle is relatively simple, and the vegetative, trophic, or nutritive stage is quite clearly marked off from the reproductive phase.

The individuals of *Monocystis* at the stage of their vegetative or trophic existence, when they are simply imbibing fluid nutriment and growing, are called **trophozoites.** One of the characteristic features of this Order is that the trophozoite commences its life as an intracellular parasite within an epithelial cell, and never in a blood-corpuscle. Within this cell it grows by absorption of nutriment contained within it, and when it has grown beyond the bounds of the cell, it bursts out from it into some cavity of its host. This may be the intestinal cavity, or a blood-space, or, as in *Monocystis*, a cœlomic space. Here it grows still more by further absorption of nutriment from the fluids of the host, and then passes on to the reproductive phase, subsequently coming back again to the trophozoite stage.

We may now pass to consider the details of the life-history of this particular parasite.

Structure and Life History of Monocystis

The life-history of any individual constitutes a cycle. It commences at a given point, and comes back again to it. The study of a cycle may be begun at any point, since in following the sequence of events which constitute it, we shall arrive again at the point from which we started. But some phases in a life cycle seem to mark themselves more obviously fitted for a beginning than others. In *Monocystis* this phase is shown in Plate II, Figs. 1 or 9. The individual at either of these two phases is a merely vegetative organism. It is absorbing nutriment from its host. Its activities are wholly those of assimilation and growth ; they are what we collectively designate as trophic. It is the period of youth of *Monocystis*. It is building up its living substance and gathering energy for later and more important work, that of reproduction. The beginning of its infancy is shown in Fig. 9, Plate II. It is seen to be at this stage a microscopic spindle-shaped organism (sp), with a centrally situated nucleus and a finely granular protoplasm. It penetrates one of the spermmorulæ (sp mr) which are floating in the fluid of the seminal vesicles of the earthworm. It gains entrance by a sort of wriggling and wave-like motion, lumping up its protoplasm at its front end, and then lengthening itself a little forwards into the protoplasm of the sperm-morula. By a succession of such movements it ultimately gains complete entrance to the central part of the morula. Here it ceases its movements and becomes wholly passive. It has now definitely entered upon the trophic stage and is called a young trophozoite. It assumes a rounded form and begins at once to absorb nutriment from the sperm-morula (Fig. 9). It doubtless achieves this by the secretion from its surface of a digestive ferment which renders the protoplasm of the sperm-morula soluble and diffusible. With nothing more to do but to feed at the expense of its host, it grows rapidly, passing from a spherical form to an oval one. It soon becomes as big as the sperm-morula, and later bigger than it. Then it inevitably bulges out the thin pellicle of the protoplasm of the sperm-morula in which it is enveloped. Ultimately the parasite is liberated entirely by the dissolution of this thin envelope, and it now floats freely for a time in the cavity of the seminal vesicle. In most cases, it later attaches itself to one of the epithelial cells of the wall of the seminal vesicle or of the ciliated rosette of the vas deferens, and continues in this situation to absorb nutriment and to grow.

By this time it has lost the oval form and has assumed an elongated one (Plate II, Fig. 1). It is now easily visible to the naked eye, so much has it grown. In *Monocystis magna* it may be a quarter of an inch in length. Examination of the trophozoite at this stage shows it to be a uninucleated organism, composed internally of a softer, granular endoplasm or medulla (Fig. 1, en), and an outer, clear, denser ectoplasm or cortex (ec). Externally, the ectoplasm is chemically and physically differentiated to form a thin but distinct cuticle. The cortex is contractile, and this enables the organism to perform certain limited movements, by which it moves from one point to another within the vesicle, or to become attached to its wall. The contractility is doubtless due to the presence in the ectoplasm of a number of exceedingly thin filaments, called the myocyte-fibrillæ. The nucleus (nu) lies in the middle of the endoplasm, and presents the appearance of a clear vesicle, containing a number of darkly staining granules, called the karyosomes. These are really concentrated grains of chromatin, which are embedded in a feebly staining substance called plastin. Karyosomes in general appearance and situation resemble the nucleoli of the cells of higher types, but, unlike them, they contain chromatin.

At a certain stage the trophic processes no longer constitute the sole function of the parasite. It passes now from adolescence to its adult stages. The passage from the one to the other is at first marked by no structural change. But some physiological alteration of great moment supervenes. It is, if we may so express it, the shadow cast by the coming events of the individual's further history. For, here as in other cases, physiological processes precede structural changes. Without any obvious or conceivable external stimuli to induce the change, we find the trophozoites now leaving their attachments to the wall of the seminal vesicles and becoming associated in pairs (Plate II, Fig. 2). It is a period comparable to that of courtship in the higher rungs of life. It is to be carefully noticed that at this stage there is no actual conjugation; it is merely one of association, or going together. The individuals at this stage are evidently entering upon a new phase of activity, and it is necessary, in our descriptive language, to distinguish them from the trophozoites. They are, therefore, called **gametocytes,** or "**marriage cells.**"

There next follows a structural change, for the gametocytes assume a rounded form (Plate II, Fig. 3), and undergo some degree of rotatory motion. Then they secrete around themselves a cyst which is common to them both. The cyst is of double thickness, consisting of an outer gelatinous coat, called the **epicyst,** and an inner thinner but tougher one, the **endocyst.**

The nucleus of each gametocyte undergoes a series of nuclear divisions by mitosis (*infra*, p. 311). The divisions are numerous and follow each other with some rapidity. The resulting nuclei are therefore very small. While these changes are going on the karyosomes become dissolved. At a certain point the divisions cease, and the small nuclei travel to the circumference or periphery of the gametocyte. Here they become regularly arranged a little way beneath the surface, and the peripheral protoplasm becomes constricted or furrowed around each nucleus (Plate II, Fig. 4). This produces a large number of little nodules (d.ga) lying upon the surface of the gametocyte, and each one of these contains a nucleus. Eventually the constrictions deepen, and cut off the nodules from the central part of the gametocytes. The single nucleated masses of protoplasm thus produced are, as we shall see, sex-cells, and are named **gametes** (Plate II, Fig. 5, ga). The central portion of the gametocyte, as a rule, contains no nuclei, and ultimately it disorganizes ; it becomes the **cystal residue.**

At this stage the cyst, which originally enclosed the two gametocytes, now contains a large number of gametes derived from them and embedded in the disorganized and slimy cystal residue. There now commences a remarkable vibratory motion of the gametes, sometimes spoken of as the "dance of the gametes." The dance slows down, and after it is finished the gametes conjugate in pairs (Plate II, Fig. 6). In Fig. 6 different stages in the act of conjugation are shown. In *a* two gametes have just come into contact. In *b* the protoplasm of the two cells is fusing, the nuclei still remaining separate. In *c* the nuclei are approaching each other. In *d* the protoplasm of the cells has completely merged, and the nuclei are beginning to fuse with each other. In *e* the act of conjugation is completed, and both cell protoplasm and nuclei are merged. A new body has now been formed. It is called the **zygote** or **sporoblast** (sp.b). It carries the potentialities of two cells, not one. It represents the beginning of a new generation.

A moment's consideration will show us that there are two possibilities in the formation of the sporoblast. Either it has been formed by the conjugation of two gametes, both derived rom the same gametocyte, or by the conjugation of two ametes, one of which is derived from one of the two ametocytes, and one from the other. There are reasons believe that the latter possibility represents the actuality.

In that case, it is clear we shall have the gametes of two different individuals conjugating.

The sporoblast, soon after its origin, begins to grow and to secrete a cyst, the **sporocyst**, around itself (Plate II, Fig. 7, sp.cy). This growth continues, and is accompanied with an alteration in form, since the sporocyst ultimately becomes an oval body with thickened extremities (Plate II, Fig. 8, sp.cy). Meanwhile the protoplasm of the sporoblast has segmented into eight little masses, each containing a nucleus. These are the **sporozoites** (Plate II, Fig. 8, sp.z). At first they are arranged around a central axis of **sporal residual** protoplasm, derived from that part of the sporoblast which took no part in the formation of the sporozoites. But later they come to lie irregularly within the sporocyst.

The condition of affairs which is now reached is this. In the seminal vesicles of an earthworm are a number of trophozoites. These associate in pairs, and then become gametocytes. Each pair forms a common cyst. Within this each gametocyte divides and produces gametes. These, by conjugation in pairs, produce sporoblasts. The sporoblasts form around themselves a sporocyst, and within this divide into eight sporozoites. The large cyst earlier formed around the paired gametocytes now therefore contains a large number (about fifty) of sporocysts and within each of these are eight sporozoites. In the seminal vesicles of the earthworm a large number of these large cysts may be found.

The next phase in the life-history is a little doubtful. The spores (sporozoites) which are destined to continue the existence of the race are enclosed within a cyst, and this is again enclosed within another. Seeing that these cysts have been formed within the seminal vesicles, it does not seem probable that they will be dissolved there. Indeed, all the evidence we have in our possession points to the conclusion that no further development occurs within this the first host. Because if it did, and each spore became a trophozoite, we should expect to see a very large number, amounting to a thousand or more, of trophozoites within the seminal vesicles. But this is not the case. It is seldom that

PLATE II

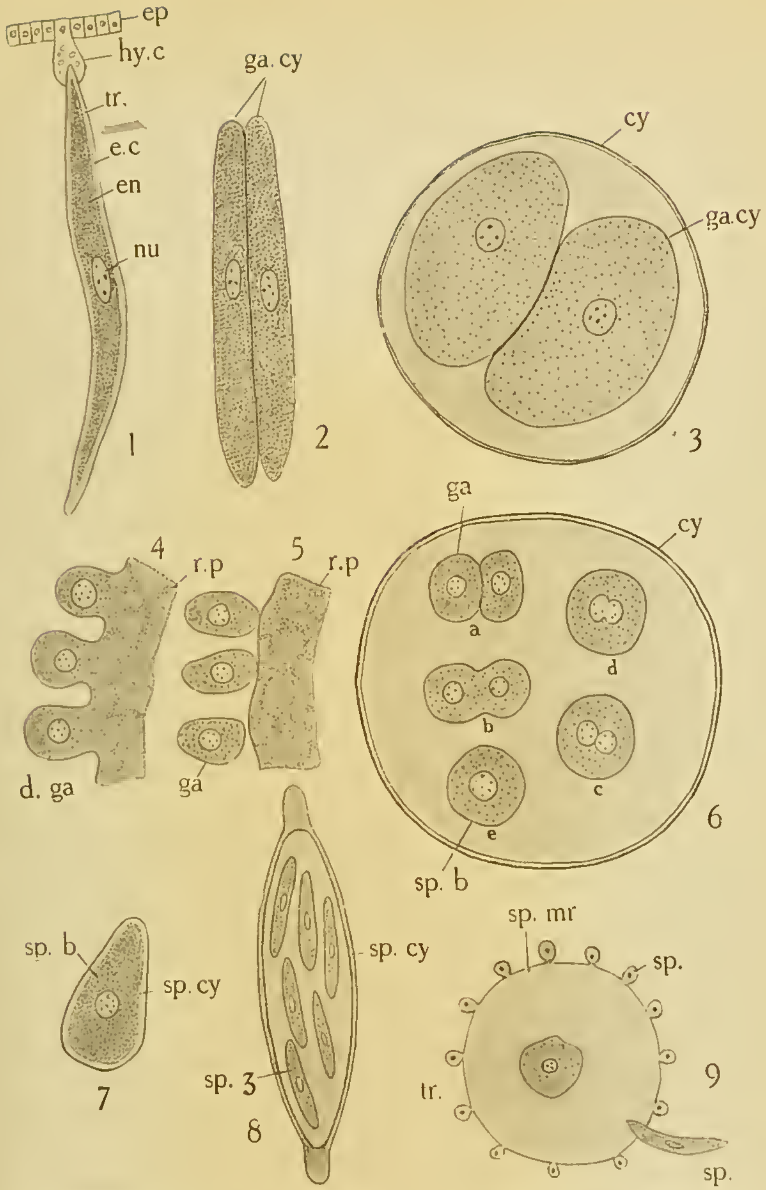


Fig. 1. Trophozoite of *Monocystis.* Fig. 2. Two associated gametocytes. Fig. 3. Two associated gametocytes enclosed in a common cyst. Figs. 4 and 5. Stages in the formation of gametes from the periphery of the gametocytes. Only a portion of each gametocyte is represented. Fig. 6. Stages in the conjugation of pairs of gametes to form sporoblasts. **a.** Two gametes paired; **b,** the protoplasm of their cells fusing; **c,** the cytoplasm completely merged and the two nuclei in touch; **d,** the two nuclei fusing; **e,** nuclei completely merged and sporoblast formed. Fig. 7. An early sporoblast encysted in a sporocyst. Fig. 8. A later sporocyst in which the sporoblast has divided into eight sporozoites. Fig. 9. A sperm-morula (spermatophore) of the earthworm showing a sporozoite entering it and one at rest within it. **cy,** cyst, showing an outer epicyst and inner endocyst; **d.ga,** gametes arising from peripheral protoplasm of gametocyte; **ec,** ectoplasm; **en,** endoplasm; **ep,** epithelium of seminal vesicle of earthworm; **ga,** gametes; **ga.cy,** gametocyte; **hy.c,** hypertrophied epithelial cell of host caused by attachment of parasite; **nu,** nucleus; **r.p,** residual protoplasm (cystal residue); **sp** (upper one in Fig. 9), spermoblast of earthworm; **sp** (lower one in Fig. 9), sporozoite entering sperm-morula; **sp.b,** sporoblast; **sp.cy,** sporocyst; **sp.mr,** sperm-morula of earthworm; **sp.z,** sporozoite.

more than about a dozen are present. We are therefore forced to conclude that infection or re-infection does not occur from within, but from without. And, if this be the case, then the sporocysts must in some way be liberated from the earthworm in which they arose.

It is not difficult to imagine the means by which this occurs. There are indeed two conceivable ways. In the first, the earthworm may be swallowed by a bird and its tissues digested. This will liberate the cysts of the parasites into the alimentary canal of the bird. The digestive fluids of birds appears to exercise no solvent action on the cysts of *Monocystis*, for they have been seen in an uninjured condition in the intestines and fæces of birds. The cysts may therefore be scattered upon the soil in the droppings of birds, and in part remain upon the surface, and in part be washed by rain down into the burrows of earthworms. In the second place, earthworms naturally die in their burrows or upon the surface of the ground. They will eventually decompose and disintegrate, and the cysts be liberated in that way.

It may, of course, be contended that since the cysts are formed within the cavity of the seminal vesicles, and since these communicate with the exterior by the vas deferens, that therefore they can be carried to the exterior when one worm is in the act of conveying its seminal fluid, through hese channels, to the spermothecæ of another worm. It at irst sight seems a very plausible way, and, indeed, almost an nevitable one, by which the cysts of the parasite should be arried to another worm. And yet there is the strange fact hat the spermothecæ of earthworms have not yet been seen o contain any stages of the life cycle of *Monocystis*.

We are thus driven to accept one or both of the two ethods we first considered. And we may therefore further ppose that an earthworm in ingesting its food or soil cidentally swallows one or more of the large cysts. In the imentary canal—probably in the intestine—this cyst is ssolved, and the sporocysts contained within it are erated. These in their turn are dissolved by the digestive juices, and the sporozoites set free into the intestinal cavity. Here they perforate the thin epithelial and muscular wall of the intestine, in the same that they enter the sperm-morulæ (*supra*, p. 78), and may find their way into a blood-vessel or into the cœlomic compartments. In the blood-vessels they may be carried round in the circulation until they reach the seminal vesicles, where they may then make a lodgment. Or, if they pass from the intestine into the cœlomic compartments, they may by their wriggling motions travel towards the seminal vesicles, and eventually enter them. It is not improbable that chemiotaxic influences may determine the path of their migration. It is conceivable, on the grounds of analogy with experimental facts quite well known in other realms of the animal and plant kingdoms, that the juices—or some substance dissolved in them—of the seminal vesicles may exercise an attractive influence upon the sporozoites, and determine the path of their motion.

Having then in one way or another entered the seminal vesicles of some other worm, they attack and penetrate the sperm-morulæ, and become young trophozoites. The life cycle is thus completed, and we have come round again to the point from which we started.

If now we take a general survey of the life cycle, and consider the part played by the reproductive processes, we shall see that they constitute a single cycle, without any distinct division into two or more clearly marked phases. The life cycle in *Monocystis* is adapted to spread its spores of infection among new hosts, these being individuals of the same species. At quite an early stage, the two spore-producing bodies, the gametocytes, become encysted, and at a later stage the spores, or sporozoites, are also developed within a cyst. They have therefore no opportunity of over-running the body of the host in which they are produced. They must pass from this first host to the alimentary canal of a second one before they can be liberated and cause another infection. But in other Sporozoa—in that genus which produces malarial fever—this is not the case. The trophozoite does not become encysted, and does not produce spores enclosed within a cyst, but it itself remains naked, and breaks up into naked spores, which can re-infect the tissues of the first host, and again becoming naked trophozoites, can, by the production of another generation of naked spores, bring about a third generation. This may proceed for many generations, until any particular organ or tissue may be completely destroyed.

Then in some cases, but not in that of the malarial fever sporozoan, the parasite resorts to the formation of spores within cysts, and these are destined to pass out from the body of the first host and to cause infection in the body of the second host. It is only this latter phase of reproduction which is represented in *Monocystis.* So that, compared with other Sporozoa, *Monocystis* manifests not two, but only one distinct phase or single cycle of reproduction. The first phase which we have just described, in which naked spores are produced by the simple splitting or multiple fission of the trophozoite, for the purposes of self-infection of the host, is called **Schizogony**, while the second phase, that in which encysted spores are formed by conjugation of gametes, for the cross infection of a second host, is called **Sporogony.** The reproductive cycle of *Monocystis*, therefore, is constituted by a Sporogony alone. We may, therefore, speak of *Monocystis* as being a **Monogenetic Sporozoan,** to distinguish it from those forms in which both a schizogony and a sporogony are represented, and which are described as being **Digenetic.**

One other feature in the life cycle calls for comment. The sexual cells or gametes (Plate II, Figs. 5 and 6, ga) in *Monocystis* which take part in conjugation are similar in form, size, structure, and behaviour. But in other forms of Sporozoa—in that of the malarial fever parasite for instance—the conjugating gametes are very different in all of these features. It s then easy to distinguish between a much smaller actively motile male gamete or microgamete, and a larger, usually passive, female gamete or macrogamete. In *Monocystis* such distinction is not possible. We may, therefore, speak of the conjugation in such parasites as *Monocystis* as being **Isogamous** and in the other forms as being **Anisogamous.**

This, of course, is a distinction applicable to other forms of life.

The life-history of *Monocystis* may be briefly summarized in a tabulated form :—

Sporozoites,
which attack a sperm-morula and become

Trophozoites.
These pair and become associated as

Gametocytes,
which enclose themselves within a cyst. They divide and form

Gametes,
which conjugate and produce

Sporoblasts.
Each of these forms a second cyst around itself, and then divides into

8 Sporozoites.

We ought not, perhaps, to leave this interesting and remarkable life-history without some attempt to portray the consequences which would ensue did there not exist in Nature a heavy destruction of all those individuals which are either "unfit" or which by reason of chance circumstances never reach their goal. In the long run this destruction results in the purification of the race. And if this is true of *Monocystis*, it is equally true of every species of animals and plants.

Let us start from a single pair of gametocytes. They ultimately produce a ripe cyst within which are, at the lowest estimate, fifty sporocysts, each containing eight sporozoites. A sporozoite is a potential trophozoite, and, therefore, in the first generation, a single pair of parents can produce 50 × 8 = 400 other trophozoites. These four hundred can produce two hundred pairs of trophozoites (gametocytes) in the next generation, and each of these pairs four hundred others. Therefore, in the second generation, the descendants of a single pair of *Monocystis*, assuming no destruction has taken place, will be 200 × 400 = 80,000. In the third generation there may be sixteen millions, and in the fourth generation three thousand two hundred million individuals. Carrying the calculation to the fifth generation, we obtain the figure of six hundred and forty thousand millions.

When we remember that almost every earthworm is infected, more or less, that most contain more than a single pair of gametocytes, and that, therefore, in any endeavour to ascertain how many individuals of *Monocystis* may be produced in five generations hence, we must multiply the figure reached above by the number of earthworms on the earth, and this by a number which shall represent the average number of pairs of gametocytes present in these worms, we begin to realize two things. First, that did not a wholesale destruction occur, there would soon be no room on the surface of the earth for any other species than *Monocystis*. And, second, we are reminded of the Malthusian doctrine that organisms tend to multiply at a rate greater than that of the means of subsistence.

Of course, this enormous rate of multiplication is not a normal one. It is a special feature of parasitic life; it is an inevitable necessity of a parasitic species which runs a gauntlet in passing from host to host, and in which many enter, but few get through. But even though we take a normal case, that of one of the slowest breeding animals—namely, the elephant—working at a minimum rate of increase, Darwin long ago showed that in the absence of any destruction except that of natural death at one hundred years of age, in 740 to 750 years there would be nearly nineteen million elephants alive, descended from a *single* pair. And in the case of the rabbit, it has been calculated that in five years the descendants of a *single* pair may number a million individuals, if no destruction other than natural death has occurred.

Clearly, therefore, if animals tend to increase at a rate which is greater than that of the means of subsistence, some kind of destruction is inevitable. Obviously, two paths are open for the operation of such a process. Either the weak, he unadapted, those lacking energy, vigour, and enjoyment of life, may be selected to live and multiply their race, while those which are strong, adapted to their inflexible and inexorable surroundings, possessed of abundant energy and inherent vigour, to whom the awakening and call of life is the signal of a joyful career, shall be destroyed, or *vice versâ*. Nature's processes are expressed in the *vice versâ*. The whole beauty of the living world is the outcome of the inexorable weeding out of the "unfit." The seeming brutality of her ruthless processes is but a veneer that covers a wholly beneficent operation. The giant beech whose roots are moored in the rifted rock and are proof against the blasts of the tempest is the beautiful product of her selection. The weakly type, whose roots could not spread deep into the rifts of a barren rock, has gone to a beneficent extinction. The Arctic tern which drops like a leaden bullet from the sky down upon the crest of a wave, espying there a fish for food, and which, unerring in sight, in capacity of direction, in rapidity of action and of instinct, never misses, is also Nature's product of selection, an emblem alike of beauty and avian virility. The erring brother, which dropped too late, misdirected its aim, or wore out its energies in plunging at shadows, has also, like the unfit beech, gone to a happy and desirable extinction.

CHAPTER XII

THE DIFFERENCES BETWEEN ANIMALS AND PLANTS

WE have now passed in review a sufficient number of the lower forms of life to understand the differences between plants and animals. It is only by a consideration of these low forms that we can arrive at an exact idea of the distinction between the animal and vegetable kingdoms, because most of the distinctions with which we are familiar in the higher forms do not hold when we try to trace them back to the lower. For instance, it is easy to distinguish between a cow and a cabbage : the animal is an actively moving form; the plant remains fixed in the soil. But some lower forms of animals, such as *Vorticella*, are usually fixed to one spot, while many of the lower plants, like *Protococcus*, have freely swimming motile phases. The cow has a compact solid shape with the chief organs embedded in the central mass of the body. It has a mouth and a stomach, a heart and blood, lungs and a nervous system, and internal generative organs. In the cabbage, the organs are not wholly aggregated into a solid mass, but appear as thin, diverging leaves and flowers and roots. The cabbage takes in food and air by roots and leaves, it has no nervous system and no blood. But all these distinctions disappear when we come to distinguish between *Protococcus* and *Amœba*. If there is any notable difference in shape the *Protococcus* is the more compact, the *Amœba* more branched and divergent. Neither has lungs or leaves, nervous system, stomach, or heart. The cow may be almost any colour ; the prevailing colour of the cabbage is green on account of the chlorophyll of the leaves ; but many plants, like the yeast plant, and most bacteria, have no chlorophyll, and are therefore devoid of the familiar green tint of plants. Cows, like all animals, take in oxygen and give out carbonic acid. Cabbages, like all green plants, in sunlight take in carbonic acid and discharge oxygen ; but we have learned that it is the property of all living protoplasm to take in oxygen and discharge carbonic acid, and, in the case of green plants, that this process is merely obscured, during the hours of sunlight, by the opposite process, due to the agency of chlorophyll. At night-time this masking influence is not operating, and it can then be demonstrated that the cabbage takes in oxygen and gives out carbonic acid. In the non-green or fungal plants, like the yeast plant and bacteria, the intake of oxygen and the excretion of carbonic dioxide is not marked by the converse process, which is a manifestation not of respiration, but of assimilation.

It will be convenient to sum up the general distinctions between animals and plants before we attempt to follow them out in the lowest forms. The usual shape of plants is branched and irregular ; their tissues grow chiefly by extension in lines and sheets. The usual shape of animals is compact and solid : their tissues grow as solid organs, forming rounded, bulky masses. The shape of an animal is therefore more or less definite and characteristic ; the shape of a plant is quite irregular and capable of extension almost in any direction. The plant, as a whole, is usually stationary. Its organs, like root-hairs, or leaves or tendrils, may have limited powers of movement, but the plant as a whole remains stationary. The animal body, on the other hand, in the vast majority of cases moves as a whole ; it is active and muscular. The whole surface of a plant exposed to the air forms the organ of respiration, and from the arrangement of the tissues in flat, thin sheets and layers, the process of respiration without special organs is rendered easy. On the other hand, the internal tissues of animals are so far removed from the outer air that special organs of circulation and respiration are present, except in simpler forms.

A plant takes in its food in the form of gases or solids in solution, by its leaves and roots. An animal takes its food in solid form by a mouth, and prepares it for absorption in a stomach. All animals require nitrogenous food in the form of protein matter, and all animals take in oxygen and discharge carbonic acid. All green plants are able to build up starch from water and the carbon dioxide of the air ; with this supply of starch they are able to build up protein, although nitrogen is supplied to them only in simple salts like nitrates. On the other hand, a few green plants, like the insect-eating plants, are able, in addition, to digest and absorb protein matter, although in their case the digestion of the protein takes place outside the plant body by means of digestive juices poured out. The fungi, being plants devoid of chlorophyll, absorb oxygen, and liberate carbon dioxide without manifesting the converse process. Like animals also, they are unable to build up starch from water and carbon dioxide, and if protein be supplied them they are able to absorb and digest it. But if starch or sugar be supplied them they are able to build up protein from a nitrogenous salt like ammonium tartrate, a piece of chemical elaboration beyond the power of any animal.

Lastly, the cells of all the higher plants have rigid cell-walls composed of cellulose or of some simple modification of cellulose. The cells of all the higher animals are, in the vast majority of cases, surrounded only by thin, elastic and delicate cell-walls, and these are never composed of cellulose nor of any modification of cellulose.

We shall find it is easy to distinguish between the simple animals and plants we have been describing. *Protococcus*, *Spirogyra*, the yeast plant, and bacteria are plants : they have cell-walls of cellulose, which are rigid and comparatively inelastic ; none of them have anything that can be compared to a mouth or stomach. Their food is absorbed as gases, and as solids dissolved in water. The two green plants build up their own starch from carbon dioxide and water, and with the addition of nitrates can form for themselves the proteins of their protoplasm. The yeast plant and most of the bacteria cannot manufacture starch. When protein matter is supplied them they will digest it and flourish ; but they will also live and grow in a solution like Pasteur's fluid, which contains no protein but nitrogen in the form of ammonium tartrate.

Amœba and *Vorticella* are animals : *Amœba* has no cell-wall in the normal condition : *Vorticella* and *Paramœcium* have a thin cell-wall : but this, like the cyst of *Amœba*, is composed not of cellulose, a carbo-hydrate, but of chitin, a nitrogenous substance.

Neither *Amœba* nor *Vorticella* can manufacture starch or build up protein from simple salts, nor can they live in Pasteur's fluid. As food, they require actual protein matter, preferably in the form of the living bodies of other organisms. These they take in as solid substances through a temporary or permanent aperture in the protoplasm, and digest in a food vacuole which forms round the food particles in the protoplasm. Another distinction is obvious in their cases. They get rid of nitrogenous waste by a special structure, the contractile vacuole. The plants have not this structure, and, in the case of these simple forms, it is not known how they get rid of their nitrogenous waste.

Although clear in the cases before us, the distinctions between plants and animals are not applicable in all cases of unicellular organisms. Some, for instance, have a cellulose cell-wall and chlorophyll, and so can live like green plants. But they also have a contractile vacuole and a mouth and pharynx, and, like *Amœba*, can ingest animal food. Others have no cell-wall, and have pseudopodia-like processes, and ingest solid food. But when they encyst, the wall of the cyst is cellulose, and the spores within the cyst have also cellulose walls.

No complete separation exists between the two kingdoms. It is most probable that animals and plants have a common origin and that some of the lower existing forms of life retain characters that afterwards became the marks of separate kingdoms, by segregation, possibly due to germinal changes in the course of evolution.

CHAPTER XIII

HIGHER PLANTS

A MINUTE green plant called *Botrydium* (Fig. 13) is not uncommon on moist mud and in ditches. As it is one or two millimetres in breadth it is quite visible to the naked eye, and consists of a green bladder-like part above the mud, joined by a narrow neck to a few short branched threads sticking in the mud. Under the microscope, one sees that it is not broken up into cells, but consists of protoplasm enclosed in a delicate wall. The green part contains chlorophyll, starch-granules, and several nuclei ; the branched part is nearly colourless. Simple as it is, *Botrydium* shows the division of labour and differentiation of function found in all the higher plants. The green bladder represents the **leaves** lifted up on a neck which represents the **stem,** so that the chlorophyll is fully exposed to light. The branching threads thrust into the mud serve as **roots**, first as an anchor or organ of attachment, and secondly to absorb from the mud salts dissolved in water.

In so simple a plant, the food materials absorbed by the green part and by the roots meet together in the general protoplasm of the body. In higher plants, the plant body is made up of a very large number of cells, and, in accordance with their different positions in the plant, these cells have different functions and different structure. Those in the leaves, for instance, have chlorophyll, and are able to break up carbon dioxide and to make starch. But, for the most part, they absorb no water and get no direct supply of nitrogen and salts. The cells of the roots absorb water and salts ; but they, having no chlorophyll, cannot use carbon dioxide nor manufacture starch. Thus a **division of labour** has taken place, and the cells, with different structures and different functions, are dependent on each other. The plant, instead of being an aggregate of independent cells, has become an organized whole with parts in dependence on each other. There is now not only the structure of cells to be examined, but the structure of the whole plant, the arrangement of the groups of cells.

In the consideration of such an organized community of cells, the first question that suggests itself is the method by which foods, obtained by one group of cells, find their way to other groups; how, for instance, the leaf cells get their nitrates or the root cells their starch. In the simpler many-celled plants there is no trace of vessels or passages along which substances might pass from cell to cell. The substances pass through the protoplasm of the cells and are handed on from cell to cell, creeping through the plant. The protoplasm of each cell is in actual connection with that of adjoining cells, so that the whole plant may be regarded as a continuous mass of protoplasm stretching through and through the cell-walls. In higher plants, such as ferns and flowering plants, there are interspaces and vessels containing air and sap, and at first sight it seems probable that gases and fluids containing nutritive substances in solution pass along by mechanical means, as gas and water circulate through the supply pipes of a town, or percolate between the cells like drainage through a gravel subsoil. But it can be shown that in a number of cases the protoplasm of contiguous cells is continuous through apertures in the cell-walls and that the apparently mechanical passage of gases and fluids through vessels and in intercellular spaces is not a mechanical passage, but that it is under control of th

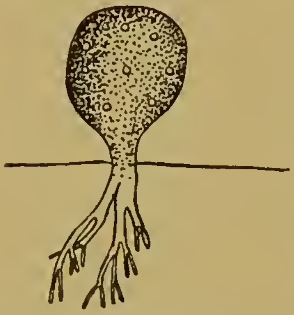


FIG. 13.—*Botrydium*: the horizontal line represents the surface of the mud above which is the green bladder containing protoplasm and several nuclei, as well as starch granules and chlorophyll; below the line are the colourless branching roots; the protoplasm is not broken up into cells by cell-walls.

protoplasm of cells, varying in amount and in the rate of passage with conditions affecting the activity of the protoplasm of the cells. For instance, the strength of the upward current of sap is much greater than could be caused by evaporation from the leaves, and for a time will go on when the leaves have been cut off. Evaporation from the leaves is not a simple mechanical process, but is controlled by the expansion and contraction of cells guarding apertures in the leaves. We shall be most near the truth if we regard the passage of substances from one part to another part of the plant as being a vital process occurring in the protoplasm of the whole plant, whether the plant be like an oak-tree, a complicated organism of many million cells, or like *Botrydium*, a simple undivided mass of protoplasm.

Retaining in our minds this general idea, it is possible to pass directly to examination of the structure of higher plants —as, for instance, of flowering plants. But this also must be borne in mind : between the flowering plants, with their great complexity of structure, and simple aggregates of cells like *Spirogyra*, there are innumerable simpler plants, which botanists have been able to arrange in a series of ascending degrees of complexity, so that they seem successive stages in the development of higher plants from lower plants. When we turn to animals we shall find a similar series and examine the stages with some care.

The growth of a plant takes place by cell-multiplication. When the protoplasm in cells increases in bulk, the nucleus and the protoplasm divide and new partition walls grow in between the dividing protoplasm as in *Spirogyra*. But in *Spirogyra* the division is always across the length of the cell, and thus threads, composed of rows of cells, are formed. In the tissues of higher plants the cells may divide across any axis according to the nature of the tissue, so that the tissue increases in length, or breadth, or thickness. So there are to be found **linear tissues**, like the vessels of plants, in which the cells have divided across their greatest length ; **flat tissues**, where the cells divide in length and breadth, as n the outside layer of a leaf ; **solid tissues**, where they divide across the length and breadth and the depth, as in the substance of a potato.

The young shoot and root of a sprouting seed are almost entirely composed of small cells, all much alike. The cells have very large nuclei and abundant protoplasm. They divide rapidly, and give rise to the various permanent tissues of the plant. This young or embryonic tissue is called **meristem** (Fig. 14), and it is from meristem tissues in the adult plant that subsequent growth of the plant takes place. At the apex of the shoot and the tip of the root, the various tissues meet in the simple meristem of these parts, from which new growth is taking place. In many plants, for instance in the dicotyledonous flowering plants as opposed to palms and grasses, which are monocotyledons, a tube of meristem called the **cambium** runs down the stem from the apex to the tip of the root and forms the growing tissue from which **wood** arises on the inside, **bast** on the outside.

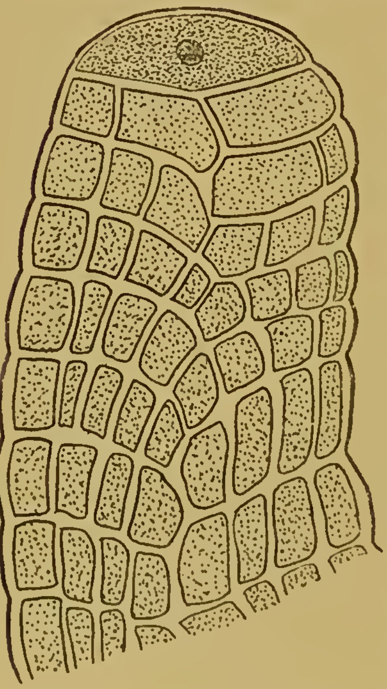


Fig. 14.—Meristem Tissue from the tip of a Leaf-shoot of *Marsilia uncinata*. The large cell at the apex has given origin to the others which are getting arranged in longitudinal rows; each cell has a thin wall surrounding the protoplasmic contents. (From Behrens.)

Other layers of meristem tissue occur in various parts of plants when there is occasion for growth. Thus the bark or cork of trees grows from a special layer of meristem cells to be found in some cases immediately under the epidermis. In fact, a young plant largely consists of a mass of meristem cells rapidly dividing. As the plant grows larger, the meristem cells in various regions become altered into the permanent cells of the adult tissues. These, however, rarely continue to multiply after they have become specialized.

CHAPTER XIV

THE GROSS MORPHOLOGY OF DICOTYLEDONOUS PLANTS

THE body of the higher plants is anatomically differentiated into **stem, leaf,** and **root.** In the lower plants no such differentiation is present, and the plant body is then known as a **thallus.** In *Spirogyra* the filamentous thread which constitutes the plant is an instance of a thallus ; the branched flattened ribbon-like bodies of a large number of common seaweeds may be mentioned as further examples.

If we examine a dicotyledonous plant, it will be seen that it consists of two portions. One of these is the root, which usually grows downwards into the soil, and the other is the **shoot,** which usually grows upwards towards the light. The shoot is not a single part, but is clearly made up of the stem with its collection of leaves. In some cases stems grow not vertically upwards but beneath the ground and in a more or less horizontal direction. Some roots, too, send branches upwards above the soil, or in some cases grow, not in soil, but in the air.

If we observe the arrangement of the leaves upon the stem it will be seen that normally the youngest are at the apex and the oldest are towards the base. And passing from the oldest to the youngest, we ascend through a series of leaves which become progressively younger as we pass up the stem. In other words, the arrangement of the leaves upon the stem is not haphazard, but is quite regular, and is such that their arrangement in space has been determined by their development in time. The oldest leaf—that which first unfolded—is the lowest leaf. This mode of succession is called

Acropetal succession. Occasionally, especially when a plant has been pruned, newer buds—which bear leaves—develop below older buds and leaves, and such departure from the normal succession is spoken of as **adventitious.**

The origin of lateral rootlets from the main root is also generally, like that of leaves, acropetal.

When we compare the shoot and the root, certain differences are apparent. The lateral organs which come off from a main root are similar in external form and in internal structure to the parent root. With the stem, on the other hand, the lateral organs (leaves) borne by it are different in external morphology and in their histology. The lateral roots do not bear other organs in their axils (namely, in the angle of the junction of lateral root with main root). Leaves do bear such other organs, which are known as buds. In the axil of all the leaves of the higher plants these buds are borne, though many become abortive and do not develop. Buds developed in the axils of leaves are called **axillary buds.** Another difference to be noted between the stem and root is in the nature of their apical termination. The root apex ends in a **root-cap,** which is a little cap-like covering of the apex of the root. It is wholly epidermal in origin. The stem is terminated by a bud. This bud in structure and origin is the same as the axillary buds, but in order to distinguish it from them on account of its position, it is called an **apical bud.**

A bud is simply an undeveloped shoot. It consists of a stem and a collection of leaves. When we examine a fully developed shoot we find, as a rule, that the leaves are more or less widely separated from each other. The points on the stem where the leaves are inserted are called **nodes** and the intervals between them **internodes.** Now the essential difference, so far as external morphology is concerned, between a bud and a developed shoot is this : in the latter the internodes have lengthened out, whereas in the former they are so short that practically they do not exist. By the elongation of its potential internodes, the bud becomes the shoot. Axillary buds thus develop into new lateral shoots, and apical buds increase the length of the stem upon which they are borne.

The higher plants, as is well known, bear **floral** or **flower shoots.** Now these shoots have the same morphological relationships that vegetative or foliage shoots have. They arise in the same way and in the same positions. We may, therefore, regard the floral axis as being a modified vegetative axis. Moreover, the parts of the flower, namely, sepals, petals, stamens, and carpels, arise like leaves, in acropetal succession. At first when they begin their development they are similar to leaves at a correspondingly early stage. And, clearly, the petals and the sepals are often very leaf-like in structure and appearance. We can, therefore, regard all the parts of the flower as being modified vegetative or foliage leaves. This conception is further borne out by the fact that not unfrequently as a variation a flower may be developed upon some part of the length of a foliage axis ; or, as it is sometimes described, the floral axis is prolonged upwards beyond the flower as a foliage shoot. Such cases have been observed in cultivated roses and in wild larches.

The higher and lower plants alike possess in a very great degree the inherent capacity of responding to wide changes in the environment. Some plants are more inherently adaptive than others. Some can respond to an increased intensity of sunlight and removal to great altitudes, such as the Summer Savory, while others, such as the flax, cannot, and therefore perish if subjected to the new conditions. Some respond to desert conditions, and survive under them, while others are inherently incapable of response and perish. And it is so with regard to all the varying factors which collectively constitute the environment of plants.

But because plants thus respond to environmental changes we must not commit the intellectual error of believing that it s the environment which produces the structural or physio- ogical changes in the plant. It should always be borne in nind, alike with plants, animals, and man, that the *capacity f responding* to environmental conditions is as much an nherent or inborn quality as the form of the leaf, the length of a canine tooth, or the erect attitude of man. If the organism does not possess this capacity of response it cannot change any of its innate qualities under the influence of a changed environment. So that in the long run—that is, in ultimate origin—what a plant will be, what it can do, what intensity of colour its flowers will have, how high or how bushy it will grow, depends not upon the environment but the inherent organization of the plant itself. It is not the fiddler's bow that brings forth musical responses from the violin, but the vibrations of the violin strings. The bow may be scraped over a block of lead, but there will be no responses of a musical order. So it is with organisms. The dwarf pea plant may be fed in the same soil and atmosphere as its tall congener, but the one will grow to about two feet high and the other to about six feet high.

CHAPTER XV

THE TISSUES OF DICOTYLEDONOUS PLANTS

THE permanent tissues of plants may be divided conveniently into three great systems, each with its own kind of specialized cells and groups of cells. The **outer or epidermal tissues** form the surface layer of the plant in its leaves, shoots, stem, and roots ; they protect it against external agencies, and regulate the intake and output of air, of water, and of food-substances. **The vascular tissues** form bundles of connecting fibres, vessels, and strands, which may be seen as the veins in a leaf, and which run through the stem and the roots, and serve as the special paths along which food-substances, water, gases, and the substances elaborated by protoplasm pass from one part of the plant to the other. **The parenchyma** or ground tissue is the mass of the leaves, and stem, and roots ; it is bounded by the epidermis on the outside, and through it the vascular bundles pass ; in it are the assimilating tissues of the plant, like the chlorophyll-containing cells of the leaf, the supporting tissues, like wood cells and the fibrous bast cells, growing tissues of unspecialized cells from which new growth is taking place, and tissues in which excretions are stored or starch laid by for future use.

THE EPIDERMAL TISSUES

The epidermis is the superficial tissue of young shoots and leaves. On the roots it cannot be distinguished readily from the underlying tissues ; on older stems and leaves it may be altered completely by structures which appear later. It is a thin layer of cells covering and protecting the young green parts of plants. It consists usually of a single layer of columnar or tabular cells regularly placed and almost invariably without chlorophyll (Figs. 15, 16, 17). The outer walls of the cells are frequently thickened, and a thin pellicle, the **cuticle,** often runs continuously over the outer surface of the cells. The material of the cuticle is very resistant to the passage of water, and differs chemically from cellulose, for it is not turned blue by iodine and sulphuric acid. Another protection against the passage of water, especially against its passage inwards, is the excretion of wax on the outer surface.

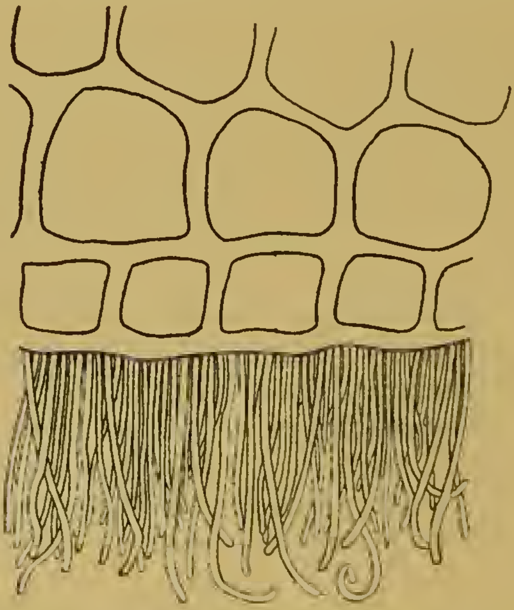


FIG. 15.—Epidermis from Sugar-cane with rod-like waxy secretion. (From Sachs.)

This wax appears as little warts or rods, and causes rain or water to collect in little drops instead of spreading over the surface of the plant and really coming in contact with the living tissues. The "bloom" on fruits is a familiar instance. But water has to pass out of the plant so that there may be room in the tissues for the intake of water absorbed by the roots and containing new supplies of inorganic salts. Everywhere on the epidermis, but especially on the under surface of the leaves, there are numbers of minute openings called

stomata (Fig. 16). If a thin piece of the epidermis from the leaf of any plant be stripped off and placed in water under the microscope, the stomata are seen at once. For they are guarded by minute oblong cells filled with chlorophyll granules and so are conspicuous, by their green colour, among the uncoloured epiderm cells. Between these **guard cells,** which are oval in shape, and usually two in number, lies a minute aperture leading into a small cavity which communicates with the intercellular spaces in the spongy tissue of the leaf (Fig. 17, 2). In damp weather, when the air is nearly saturated with moisture, the guard cells alter their positions so as to open the stomata as widely as possible. In bright sunshine too, even though the weather is dry, the guard cells may at first leave the stomata widely open, but afterwards, if the escape of water is too rapid, they may contract the apertures to the smallest point.

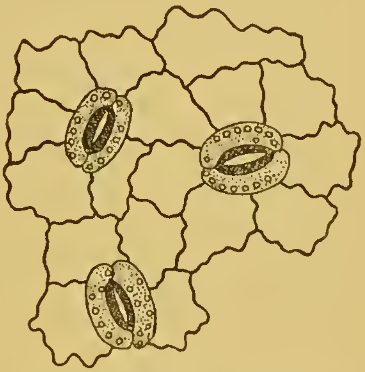


FIG. 16. — Epidermis from under surface of a lilac leaf, showing three Stomata, each enclosed by a pair of guard cells.

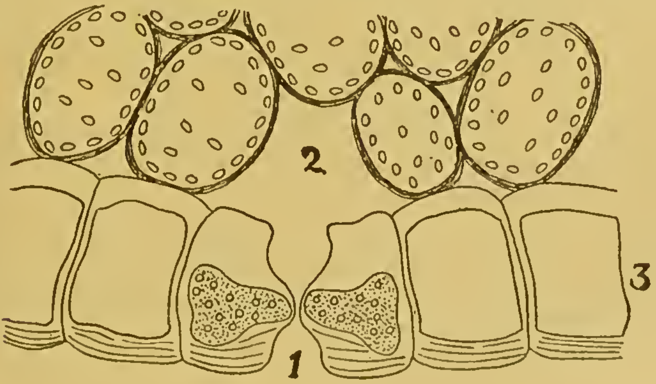


FIG. 17.—Vertical Section through a Stoma on the under surface of a leaf. 1. Aperture between the guard-cells. 2. Intercellular space communicating with spaces among the parenchyma cells. 3. Epidermis cells with cuticle as the lower (outer) border. (After Sachs.)

The stomata normally serve for the transpiration of gases, especially of water-vapour and of oxygen. They also allow of the passage inwards of the atmospheric gases, partly for purposes of respiration and partly for those of assimilation. In a few cases, stomata situated at the edges of leaves serve for the extrusion of water in the liquid state.

The **hairs** of plants are outgrowths from the epidermis. At first, hairs are mere processes from single epiderm cells and may permanently remain as unicellular appendages; but by growth and cell-division they may be changed into multicellular organs. Some hairs are glandular, and in a little knob at the end of the outgrowths is collected the secretion of oil, or resin, or gum. In some cases, as in the nettle, an acrid secretion with irritant properties is collected, and liberated when the hair is broken off.

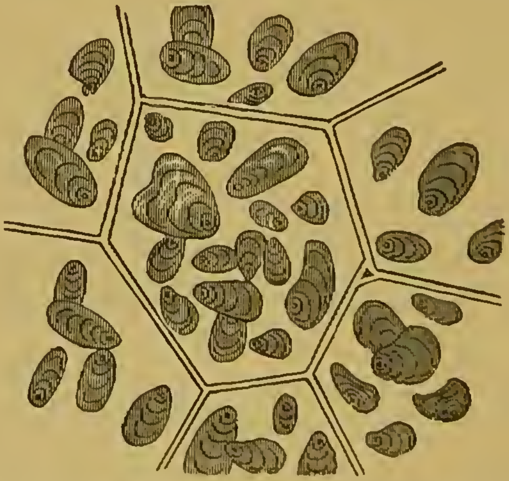


FIG. 18.—Parenchyma from potato tuber containing starch granules.

THE GROUND OR FUNDAMENTAL TISSUES

The fundamental or general tissue of plants consists in its simplest and most common form of irregularly shaped thin-walled cells—called **parenchymatous** cells. It may be seen in any young plant practically occupying all the space within the epidermis (Fig. 27, 3)—except of course the space occupied by the vascular bundles and other special tissues. In the typical condition, the cells are large, and are actively multiplying. Later their multiplication ceases. Where cells are in contact, a single cell-wall separates them, but at the angles where three cells meet, interspaces occur, due to splits in the cell-wall. These are the intercellular spaces, and allow the movements of gases and water-vapour throughout the plant. The cells contain protoplasm and a nucleus, but the products formed by the protoplasm are so plentiful that the protoplasm itself only occupies a narrow area within the cell-wall. It forms a film, the **primordial utricle**, upon the inner surface of the cell-wall. The central space or vacuole is occupied by a watery juice or cell sap full of substances of nutritive value. Reserve food materials like the starch in the tubers of the potato, in the pith of young plants, or in seeds are to be found in parenchymatous cells (Fig. 18). Frequently in old plants, and in old tissues of plants, there are to be found parenchymatous cells practically dead. The protoplasm, the sap and starch grains have disappeared, and the cell-walls remain behind as a spongy pith filled with air.

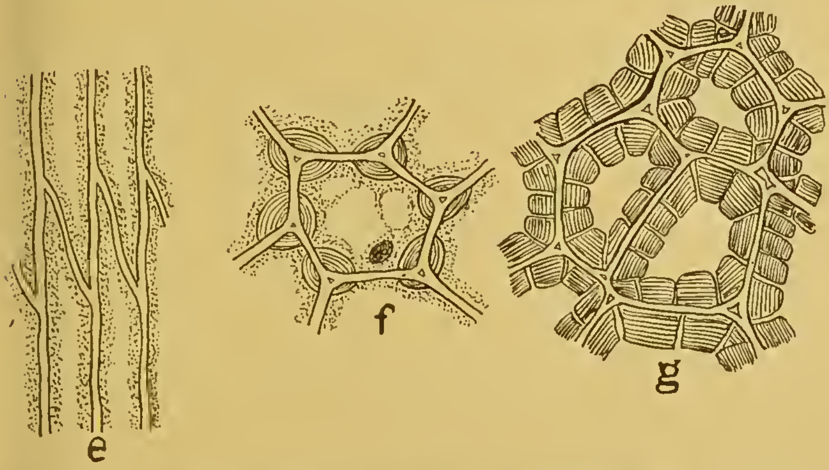


FIG. 19.—**e.** The overlapping ends of prosenchymatous cells. **f.** Collenchymatous cells. **g.** Sclerenchymatous cells.

When the cells of fundamental tissue are elongated they may have overlapping ends, and are called **prosenchy-**

matous cells (Fig. 19, *e*). When they have pad-like thickenings of the cell-wall at the angles where cells are in contact, they are known as **collenchymatous** cells (Fig. 19, *f*); and where the whole cell-wall is excessively thickened and partly turned into wood, the tissue is called sclerenchyma—the cells **sclerenchymatous** cells (Fig. 19, *g*). These names are merely descriptive, and are applied to cells of different natures in different parts of a plant. Thus the cells forming the hard nodules in the flesh of pears have their walls lignified, and are sclerenchymatous; the elastic fibres of the bast (hard bast) have thick walls not lignified, and are also sclerenchymatous; while the cell-walls of the "bundle" sheath found surrounding the vascular bundle in young stems are frequently lignified, and are again named "sclerenchymatous." A very characteristic feature in the thick walls of sclerenchyma is the presence of small canals formed from pits.

It is in fundamental tissue that most of the chlorophyll of green plants is to be found. Obviously, as the usefulness of chlorophyll depends on its exposure to light, it is found in the leaves and in the stem. As, moreover, the utility of chlorophyll depends on the ready access of air in order that the carbonic acid may be absorbed, the tissues containing chlorophyll have for the most part a loose and almost spongy arrangement of cells. The interspaces between the cells are in free connection with each other and with the stomata, so that the stomata, while serving chiefly for the transpiration of water-vapour, are a ready means for entrance of air. Such a spongy structure is well seen in a section through the leaf of a plant (Figs. 17 and 29).

Collenchymatous and sclerenchymatous tissues have chiefly mechanical functions to fulfil. They are found where any organ or part of an organ of a plant is subjected to stress, or where rigid structures are necessary for purposes of defence. Thus we find two cylinders of these mechanical tissues in the stem of the Bryony. This plant has a long, climbing and slender stem. Were it composed of parenchymatous ground tissue alone, it would soon be damaged. But immediately within the epidermis is a cylinder of collenchyma, and a little way within this is another of sclerenchyma. The long and relatively thin stem of the sunflower presents a similar condition, though here the sclerenchymatous cylinder is broken up into separate strands. On the other hand, such massive organs as potatoes, resting in and supported all round by soil, do not possess any of these mechanical tissues.

The cells of the epidermis frequently have the cellulose of their outer walls changed to **cork** to prevent evaporation of sap. After the first or second year of their existence very many plants develop a thick layer of cork cells within the epidermal layer, which dies. Cells in a row under the epidermis multiply rapidly, and the layers of cells to which they give rise form a compact tissue with no spaces between the cell-walls. The contents of the cork cells disappear and become replaced by air ; the walls of the cells change from cellulose to cork, and the tissue forms a thick protective layer completely resistant to the passage of water (Fig. 21).

THE VASCULAR TISSUES

The second system of tissues, the **vascular bundles,** is so characteristic of higher plants that, in classification of the vegetable kingdom, those without vascular bundles (the Algæ, Fungi, Lichens, Liverworts, and Mosses) are distinguished as *cellular* plants from the *vascular plants* (Ferns, Lycopodiums, Equisetaceæ, &c., and the seed-plants). Even in the cellular plants, however, not infrequently there are tracts or bundles of elongated thin-walled cells, distinct from the tissue in which they are embedded, and serving as the main channels along which

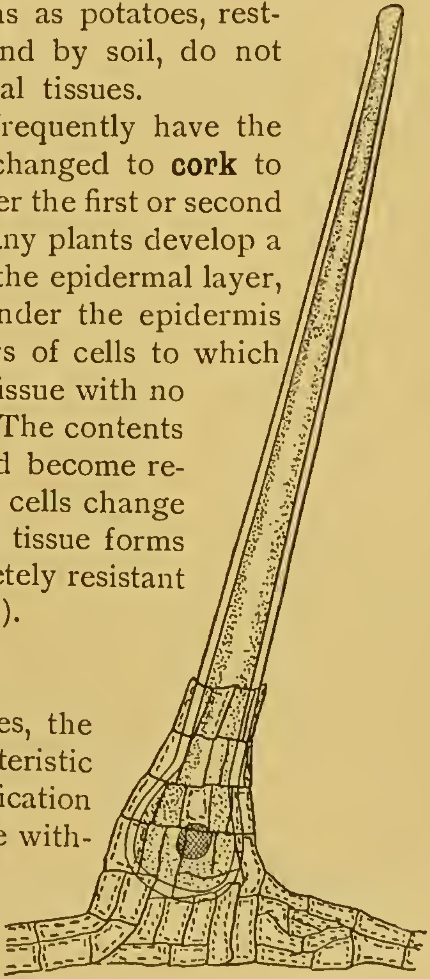


FIG. 20.—Stinging-hair of nettle. This is a single elongated cell with nucleus in the bulbous root which is surrounded and protected by epiderm cells.

substances pass from part to part of the plant. The vascular bundles of vascular plants (Fig. 22) run as thin threads of specialized tissue through the whole plant. In the root there is usually a central cylinder lying in the axis and receiving branches from the lateral roots. The vascular strands of the roots pass into those of the stem, which are usually symmetrically arranged round the periphery. These give off branches to the leaves, and pass into the growing point at the apex of the stem, where they lose themselves in unspecialized cell tissue. The details of their arrangement in the stem vary much in different plants, and depend on the arrangement of the leaves. The separate bundles are placed round the margin of the stem: between the nodes, or where leaves grow out, they appear as separate wedge-shaped masses; at the nodes they fuse together, and the branches for the leaves are given off.

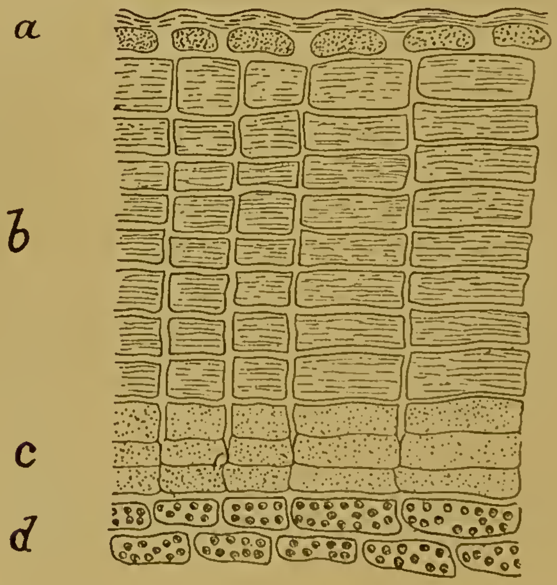


FIG. 21.—Section through one-year-old shoot of *Aïlanthus glandulosa*, showing, **a**. Dead epidermis. **b**. Cork cells. **c**. Cork cambium. **d**. Cortex cells with chlorophyll granules. (After Prantl.)

We must now consider the **Vascular Tissues.** These are composed of very specialized cells. At the apex of the stem or root they become arranged in vertical rows, and by the complete or partial absorption of their transverse walls they soon become converted into tubes or **vessels,** extending throughout the whole length of the stem and root.

There are two chief kinds of vessels, namely, **sieve-tubes** or **phloem vessels,** and **xylem vessels.** Other types of vessels exist in plants, but we are not now concerned with them.

A sieve-tube is, as its name implies, a tube. It has been formed by the superposition of cells (Fig. 23, *c*) in a serial arrangement. At the apex of both stem and root they are continually added to by the addition of new cells from the apical meristem. The tube thus increases in length simultaneously with the increase of the stem and root. After the new cells have been added, they themselves grow in length, their protoplasm becomes extended out into a thin film which lines their internal walls, and the transverse upper and lower wall of each cell become perforated by a number of perforations (Fig. 23, *b*). In this way, although the cells are joined end to end, there is not formed, as we shall see later is the case with the xylem

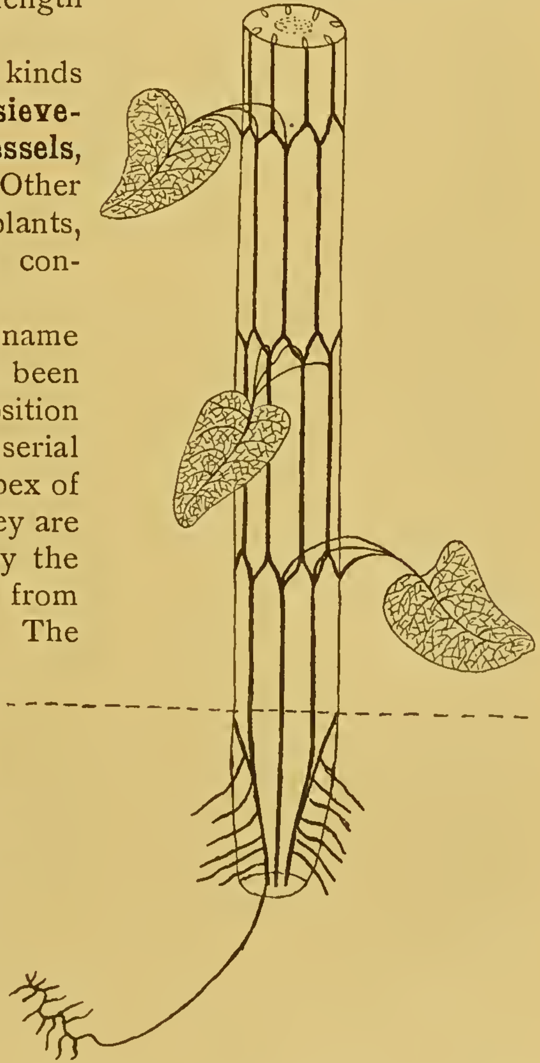


FIG. 22.—Diagram of the course of vascular bundles in stem, leaves, and roots.

vessels, a continuous tube, but a tube divided into compartments, which open into each other by means of their perforated plates. These are called **sieve-plates** (Fig. 24). They do not remain unthickened, like the longitudinal walls, but become strengthened by a deposit of material called **callus.**

These transverse plates are not the only sieve-plates present. For generally, where two sieve-tubes come into contact, there are formed localized patches along the course of the opposed walls, which become thickened by callus and perforated by little tubes. Sieve-plates situated upon the longitudinal walls are called lateral sieve-plates.

The sieve-tubes not only contain a thin film of protoplasm, with a nucleus in each of the compartments, but in life their cavities are filled with a slimy, nitrogenous material, which represents the elaborated food-substances of the plant. When the plant is placed into alcohol, for preservation, this slimy material coagulates and contracts and forms a central rod of stuff extending from one sieve-plate to another. This material is represented in Fig. 24 by the dotted core.

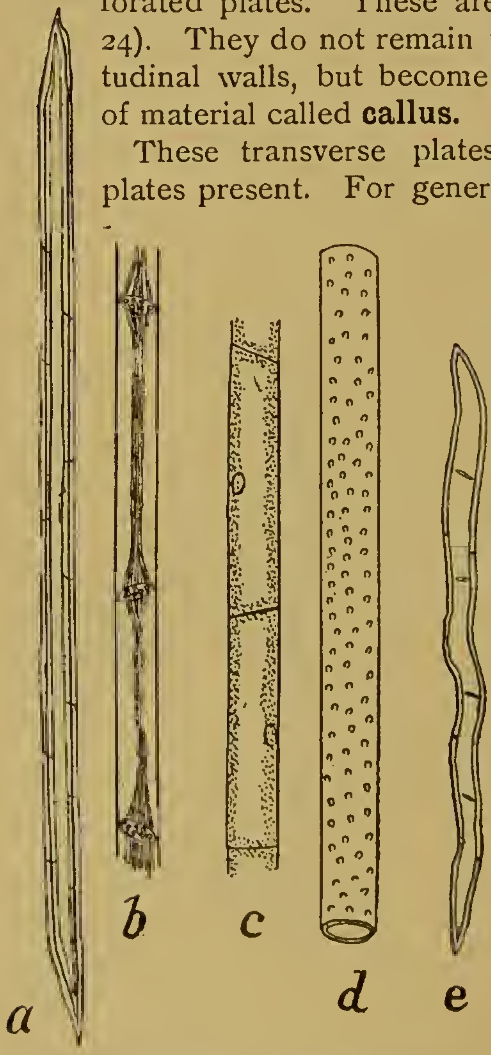


Fig. 23.—Isolated cells from a vascular bundle. **c.** Cambium cells. **b.** Sieve-tube. **a.** Bast fibre. **d.** Dotted wood-vessel. **e.** Wood cell. **a** and **b**, the bast elements, and **d** and **e**, wood elements, have alike been formed from cells like **c.**

The protoplasm of the different compartments is continuous.

We must therefore picture the protoplasmic film of the various sieve-tubes as extending uninterruptedly throughout the whole length of the plant. It is known in other cases that the protoplasm of adjacent cells is in organic continuity, by filaments of its substance which pass from cell to cell through perforations in the cell-walls. Arising out of these and other facts has come the conception of the **Continuity of Protoplasm.** It is thought that an organism must be conceived as consisting not of isolated cells bound together by cement substance, but of a network of protoplasm, which is supported by more or less rigid cell-walls, cement substance, or other skeletal structures. In connection with this conception the student should refer to the chapter on Histology, and note the facts in connection with unstriped muscle, striped muscle, cardiac muscle, the bone corpuscles and the concrescence of Held (p. 271). In all these instances we have examples, more or less definite, of a limited degree of continuity of protoplasm. But the continuity of protoplasm within the area of a particular tissue, or of particular tracts of a specific tissue, does not necessarily imply that the whole organism is an example of such continuity.

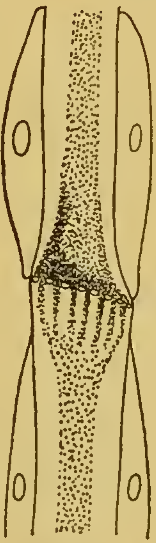


FIG. 24.—Enlarged view of longitudinal section through a sieve-tube in the region of a sieve-plate. On either side of the sieve-tube lie *companion cells.*

To come back to the sieve-tubes. They are, in the higher plants, accompanied with long cells, full of a densely granular protoplasm and containing a nucleus. These cells have thin cellulose walls, and are arranged in rows along he sides of the sieve-tubes. They are "reservoirs," and very probably also "manufacturers," of nitrogenous food material. They arise by the division of the same cambial daughter cell from which the particular compartment of the ieve-tube to which they are attached took its origin. That is the reason why in transverse sections of the stem they often ook as though they had been cut off from the sieve-tube.

The **xylem vessels** are seemingly rather more complex than the sieve-tubes. They arise in the same way by the superposition of cells in vertical rows. But in this case the transverse walls, as a rule, become wholly absorbed. Continuous tubular vessels are thus produced.

At first the cells that are destined to become part of a xylem vessel have abundant protoplasm, a nucleus, and a thin cellulose wall. But as development proceeds and the transition from cell to vessel takes place, the protoplasm becomes progressively reduced and the wall of the cell is thickened by a deposit of woody substance called **lignin.**

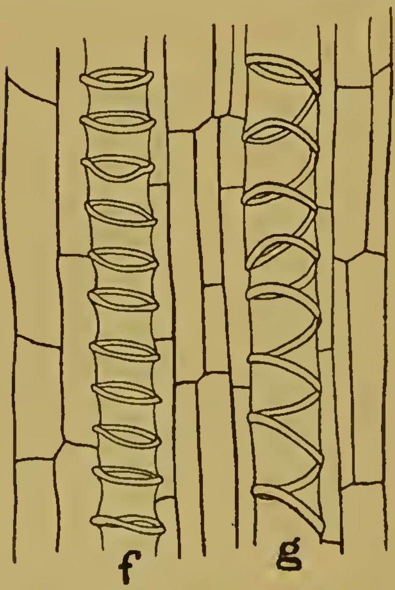


FIG. 25.—Longitudinal section through the xylem of vascular bundle from *Impatiens balsamiac*, showing: **g**, spiral, and **f**, annular vessels.

The deposition of this lignin upon the inner surface of the primary cellulose cell-wall does not occur uniformly. It may indeed assume various forms. The most simple is when rings of wood are laid down at intervals within the wall of the vessel. Such a vessel is distinguished as an **annular vessel.**

Equally simple is the case where the woody deposit takes the form of a thread or string spirally wound round within the wall. In these cases we call the vessels **spiral.**

In other vessels the deposit is laid down in successively very thin layers, each being perforated by a number of pores. And as each layer is deposited the pores in the one correspond in size and position to those in the others. The primary cellulose wall thus becomes thickened by a more or less thick, uniform layer of wood, the whole thickness of which is perforated by tubular pores. The primary cellulose wall is not perforated, so that the cavities of contiguous vessels are not in actual communication, but are separated by this thin primary film. Vessels of this kind having walls traversed by simple tubular pits, under the microscope present a dotted appearance, and are called "**dotted**" or **simple-pitted vessels.**

But there is another type of pitted vessel, in which the pits are not of the simple tubular kind, but have the form of the space which is enclosed when two watch-glasses are placed edgewise together. It has been formed in the same way as the sample pit, but instead of the deposited layers having their respective perforations of equal size, they become progressively smaller with each successive layer. Such pits when seen under the microscope show a bright centre, which is the actual orifice of the pit or perforation of the last deposited layer. This is surrounded by the border (the optical expression of the base of the pit or widest perforation of the first deposited layer). The vessels containing such pits are therefore called **bordered-pitted vessels.**

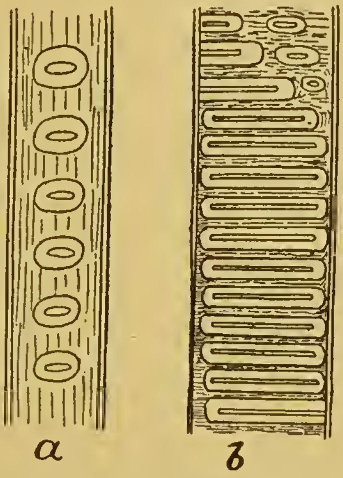


FIG. 26.—Diagram of bordered pits and scalariform vessel. **a.** Vessel with bordered pits. **b.** Scalariform vessel with elongated bordered pits.

In some pitted vessels the pits are lengthened out into slit-like issures. They are usually arranged n a vertical series, like the rungs in ladder, and hence the vessels are alled **scalariform vessels.**

That the walls of a thickened essel are not merely homogeneous, but are composed of uccessive layers, can sometimes be easily seen, especially in ery thick-walled woody elements, such as may be found in ie xylem of the bracken fern. Here the walls are clearly ratified or lamellar in structure.

Some prosenchymatous cells become thickened by woody eposits and their walls perforated by simple pits. We ive seen that when any woody tissue (composed either of osenchymatous or parenchymatous cells) occurs in the ndamental or ground tissue, it is called sclerenchyma.

But when woody prosenchymatous cells appear in the vascular tissues they are called **wood-** or **xylem fibres**.

They are mostly cells in which the protoplasm has completely disappeared. The wood fibres sometimes are so twisted and matted that even in a longitudinal section the whole length of a cell rarely appears.

CHAPTER XVI

THE STRUCTURE OF THE STEM

EXAMINATION of a transverse section of the stem of most dicotyledonous herbaceous plants, such as that of the Bryony or Sunflower, will show that externally it is limited by a thin membrane, the **epidermis** (Text-figs. 27 and 28, and Plate III, ep). This is composed of a single layer of oblong or square cells, which contain protoplasm and a nucleus, but as a rule are devoid of chloroplastids. The epidermis usually bears hairs of various sorts, either unicellular or multicellular, or both. It is also pierced by stomata, which are encircled by modified epidermal cells, the **guard cells.** The general description of this tissue of the stem has been already considered (*supra*, p. 101).

Within the epidermis lies the **cortex** (Plate III, cor) composed of the cortical or **extra-stelar ground tissue.** In both types of stem which we are considering (Bryony and Sunflower) the outer layers of the cortex consist of collenchyma (coll), which forms a cylinder of mechanical tissue. But this collenchymatous zone is not merely a dead and mechanical tissue, for it is also living and assimilatory. Its cells contain protoplasm and chloroplastids. The presence of these two bodies is evidence of the existence of assimi-atory functions. Within the collenchymatous zone there s in Bryony a narrower, and in the Sunflower a wider one of undifferentiated parenchyma (p), with intercellular paces (in.s). These communicate with the exterior through he similar spaces which lie in the collenchyma just beneath ach stoma. The cells of this cortical parenchyma also con-ain protoplasm, a nucleus, and chloroplastids, and it is one f the chief assimilatory tissues of a herbaceous stem. In some cases the innermost layer of the cortical parenchyma is clearly differentiated in the form and size of its cells from the rest of the tissue. In other cases there is no obvious difference. This innermost layer of the cortex is distinguished by the term **bundle-sheath** or **endodermis** (en).

The central part of the stem, that is all which is enclosed within the endodermis, is occupied by a vascular cylinder called the **stele**. In other words, the stele is a cylinder enclosing the main strands of the vascular tissues. The wall of this cylinder is called the **pericycle** (per).

Two types of pericycle may be recognized. In the first the tissue is all of one kind, either sclerenchyma or parenchyma. This kind of pericycle is called **homogeneous**. Such a type is present in **Bryony**, where the pericycle consists of some three to seven layers of sclerenchymatous cells. In the Sunflower, on the other hand, we have a **heterogeneous** type of **pericycle**. In this case it consists of two kinds of tissues. There are the sclerenchymatous strands running down on the outer side of the vascular bundles; alternating with them are parenchymatous strands which fill up the gaps between.

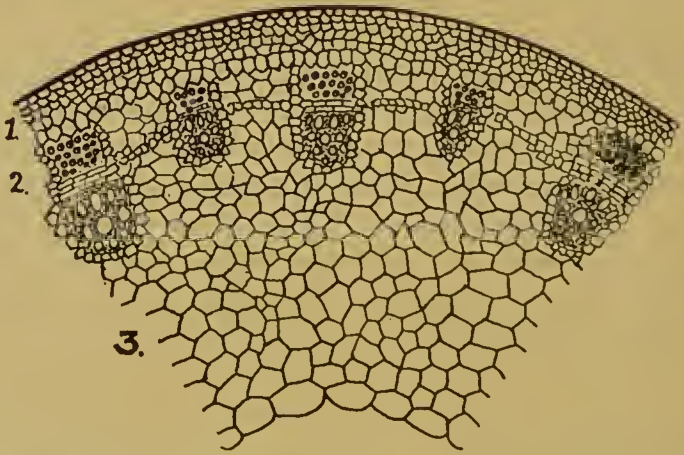
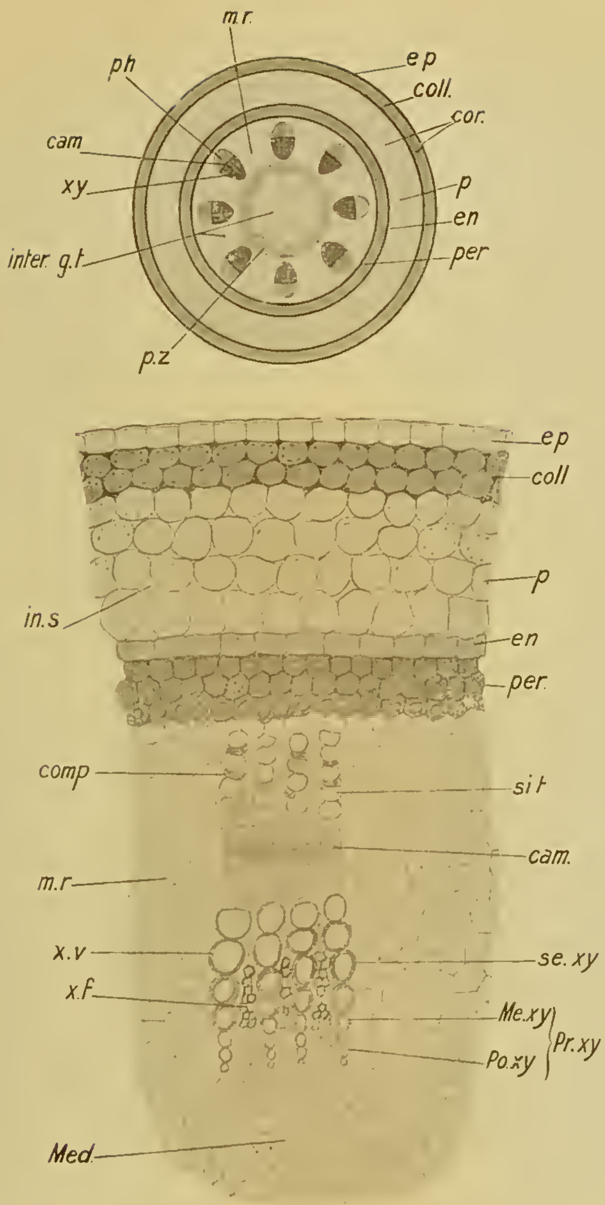


FIG. 27.—Part of a transverse section through the stem of a dahlia, showing: 1. The epidermis. 2. Five vascular bundles. 3. Parenchymatous tissue.

We may regard such a pericycle as being originally homogeneous and parenchymatous. Its differentiated con-

PLATE III



Upper figure. Transverse section of stem of a dicotyledon diagrammatically represented. Lower figure. Portion of a transverse section of the same stem showing the histological detail and including one vascular bundle. **cam,** cambium; **coll,** collenchyma; **comp,** companion cell; **cor,** cortex; **ep,** epidermis; **en,** endodermis (bundle sheath); **inter.g.t,** intrastelar ground tissue; **in.s,** intercellular spaces; **med,** medulla or pith; **me.xy,** metaxylem; **m.r,** medullary ray; **p.,** parenchymatous portion of cortex; **per,** pericycle; **ph,** phloem; **po.xy,** protoxylem; **pr.xy,** primary xylem; **p.z,** perimedullary zone; **se.xy,** secondary xylem; **si.t,** sieve tubes; **xy,** xylem of vascular bundle; **x.f,** xylem fibres; **x.v,** xylem vessels.

dition is due to the development of hard tracts of sclerenchyma in it as the pericycle becomes older. Or we may regard it as a sclerenchymatous pericycle which has become broken up in the areas between the vascular bundles so that the cortical tissues are in free communication with the medulla. Under this conception, the idea of the existence of a stele no longer holds, and we should designate the condition as one of **astely.**

A heterogeneous pericycle need not necessarily be composed of the two particular tissues mentioned, *i.e.*, sclerenchyma and parenchyma. In other cases, we find it consists of parenchyma and glandular tissues, such as resin ducts.

In the stem the pericycle is nearly always multilayered, while in the root of the higher plants[1] it is usually single-layered, with sometimes a tendency here and there to become two-layered.

Within the pericycle are two chief tissues, the **intrastelar ground tissue** or the **conjunctive parenchyma** and the **vascular tissues.** These latter run in the form of definite tracts or bundles of tissue, and are hence called **vascular bundles.**

STRUCTURE OF VASCULAR BUNDLES

In a dicotyledon three tissues take part in the constitution of a vascular bundle. They are the **phloem** on the outside, he **xylem** on the inside, with the **cambium** between he two.

The phloem is made up of three elements. The chief onstituent is the collection of **sieve-tubes** (Plate III, si.t). Next are the **companion cells** (comp). And last is the **phloem parenchyma,** which acts as a sort of packing tissue olding the other two tissues together in a coherent strand. Of course, this phloem parenchyma should not be regarded s a merely passive tissue. It constitutes tracks along which ertain food materials may travel by diffusion, and, like the ther two tissues, it is also living.

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[1] The *Dicotyledons* and *Monocotyledons*. In some *Gymnosperms* (Firs) is multilayered.

Three tissue elements also take part in the formation of the **xylem.** There are the **xylem vessels** (x.v) with large cavities, the smaller **xylem fibres** (x.f) and the **xylem parenchyma.**

An examination of a transverse section of a stem shows that the xylem vessels are more or less radially arranged and that the more central ones on each ray are smaller than the outer ones. In a longitudinal section of the vascular bundle the most central and smallest vessels are of the spiral and annular types, while the smaller ones immediately

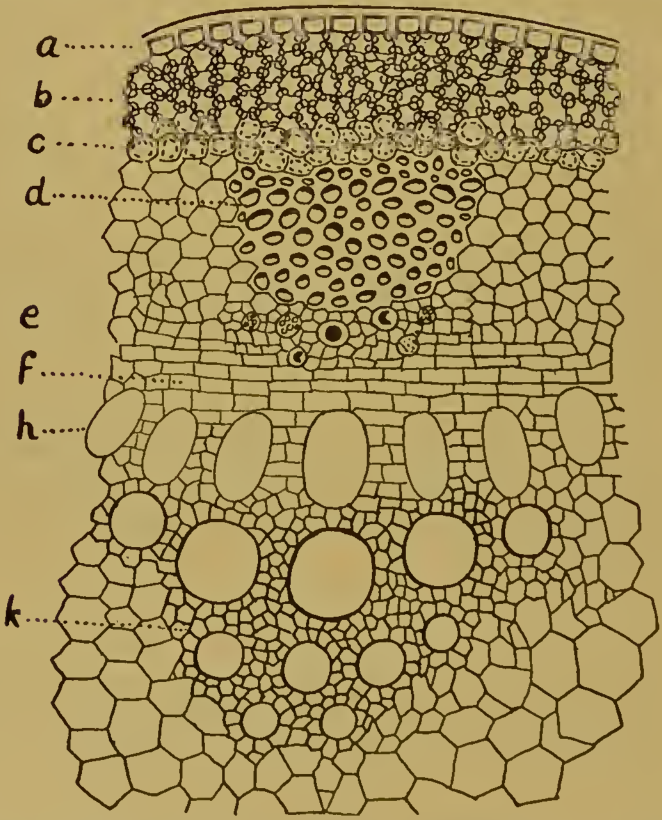

FIG. 28.—A single bundle from Fig. 27, enlarged. **a.** Epidermis with cuticle. **b.** Collenchymatous cells. **c.** Cells with chlorophyll. **d.** Hard bast or pericycle fibres; below this, opposite **e**, is soft bast parenchyma containing sieve-tubes, some cut across through the sieve-plates, others cut through the albuminous mass stretching between the sieve-plates. **f.** Cambium. **h.** Outer row of wood-vessels; nearer the centre are three other rows containing a diminishing number of vessels. **k.** Wood parenchyma.

without them are pitted vessels. This central portion is the **primary xylem** (Pr.xy), and it has a different origin and is formed earlier than the rest of the xylem. The remaining or outer portion is known as **secondary xylem.**

The primary xylem is formed at the apical region of the stem, and the secondary xylem does not arise until some time after the primary and some way down the stem, well below the apical region. Transverse sections, taken on the apical region of a stem, or a little way behind it, will therefore show primary xylem alone. It would be necessary to take sections some way down the stem before secondary xylem could be seen.

Primary xylem is formed from an **apical meristem,** or genetic tissue situated at the apex of the stem. Secondary xylem is developed from the cambium, which is a genetic tissue lying between the phloem and cambium of the vascular bundles.

The primary, like the secondary xylem when it is first developed consists of thin-walled cells or tubes. Before these can become xylem they must be lignified. Now it is known by a study of serial sections taken through the apical region of a stem, that the central portion of the primary xylem lignifies before its outer part. This first-formed portion of the xylem consists of annular and spiral vessels and is called the **protoxylem** (Po.xy). The other and outwardly situated part of the primary xylem lignifies at a later stage and consists of pitted vessels. It is called the **metaxylem** (Me.xy).

We see that the development of the primary xylem thus proceeds from within to without. It follows a **centrifugal direction.** Now in the root, we have the same distinction into protoxylem and metaxylem of the primary xylem, but there the development is from without to within, or **centripetal in direction.** The protoxylem in the root is thus outside the metaxylem and not inside as in the stem.

The phloem like the xylem is divisible into primary and secondary portions upon precisely the same grounds. And the primary phloem also differentiates in two periods; but with this tissue the protophloem lies outwardly and the metaxylem inwardly.

We must not fail to observe that, owing to the mode of formation of secondary vascular tissues, the primary xylem lies to the extreme inner edge of the secondary xylem, while the primary phloem lies to the extreme outer side of the secondary phloem. We mention the point here, as a fact, but the student will understand the reason of it when we consider the nature of the cambium.

THE CAMBIUM

The cambium (Plate III, cam) is a permanently genetic tissue situated between the phloem and the xylem. It consists of **mother cells,** which perennially divide and produce **daughter cells.** The latter may be able to divide perhaps once or twice after they are cut off from their mother cells, but their capacity for division is strictly limited. That of the mother cell, on the contrary, so long as it lives, is unlimited.

The fate of the daughter cells is somewhat curious when we remember that they all come from similar mother cells. If a daughter cell is budded off to the outer side of the mother cell, it ultimately develops into one of the three constituents of the phloem, namely, a companion cell, a phloem parenchyma cell, or it adds one compartment to a sieve-tube. If the daughter cell is budded off towards the inner side of the mother cell it develops into one of the three constituents of the secondary xylem, namely, a wood fibre, a xylem parenchyma cell, or contributes to the formation of a xylem vessel. The generalization that the cambial mother cell is thus continually dividing and cutting off daughter cells, sometimes to the outside and sometimes to the inside, and that the former give rise to phloem elements and the latter to xylem elements, is known as **Sanio's Law.**

THE INTRA-STELAR GROUND TISSUE

The intra-stelar ground tissue or conjunctive parenchyma (conjunctiva) may be divided into two portions. There is a central part, occupying the axis of the stele and filling up the central core invested by the vascular bundles, and consisting of a large-celled parenchyma. This is called the **medulla** or **pith** (med). The other part consists of a parenchyma of smaller cells, and it fills up the spaces between the vascular bundles. Each tract which lies between any two vascular bundles is called a **medullary ray** (mr). In some stems the medulla or pith is clearly bounded by a definite cylinder of a small-celled parenchyma, which lies just within the vascular zone. This is called the **perimedullary zone** or **endocycle** (pz).

CHAPTER XVII

THE STRUCTURE OF THE LEAF

THE minute structure of a typical dicotyledonous leaf may be seen in a transverse section of the leaf of a beech or of a holly. We will describe the former first. The outer surface of the leaf is composed of a unilayered membrane, the **epidermis.** The general features of this tissue we have already considered. Here we need only note certain special features which characterize the epidermis of this particular leaf. The leaf being thin and flat has obviously an upper and lower surface. The epidermis of the two surfaces is different. The cells of the upper epidermis (Fig. 29) are large and squarish, while those of the lower surface are smaller, flatter, and approximately rectangular in form. In the cells of both layers chlorophyll grains are absent. Moreover, the upper surface is devoid of stomata, while they are present in large numbers upon the under surface.

Between the upper and lower epidermis is the **mesophyll** or "**middle-leaf.**" In most dicotyledons this part of the leaf is differentiated into an upper **palisade layer** and a lower **spongy parenchyma.** The former is made up of a single layer of long column-shaped cells with their length arranged at right angles to the surface of the leaf. Numerous chlorophyll grains are present in these cells, and they are arranged in a single layer, lying in the protoplasm just within the cell-wall. This mode of arrangement, instead of, for instance, being packed in a central mass, allows every chlorophyll grain to receive some at least of the rays of light falling upon the surface of the leaf. Not only that, but the cells of the palisade layer, although regularly arranged, are not continuously cemented to each other, like the bricks in a wall, but are loosely packed, so that a slight space separates the cells from each other. Into these spaces the atmospheric air, with its carbon-dioxide gas, finds its way. Now, one of the functions of the chlorophyll grains is to utilize this carbon-dioxide for purposes of nutrition. And clearly, when the grains are arranged in a single layer upon the surface of the cell-wall, the facility for taking up the carbon dioxide is much greater than if they mutually interfered with each other by being massed together.

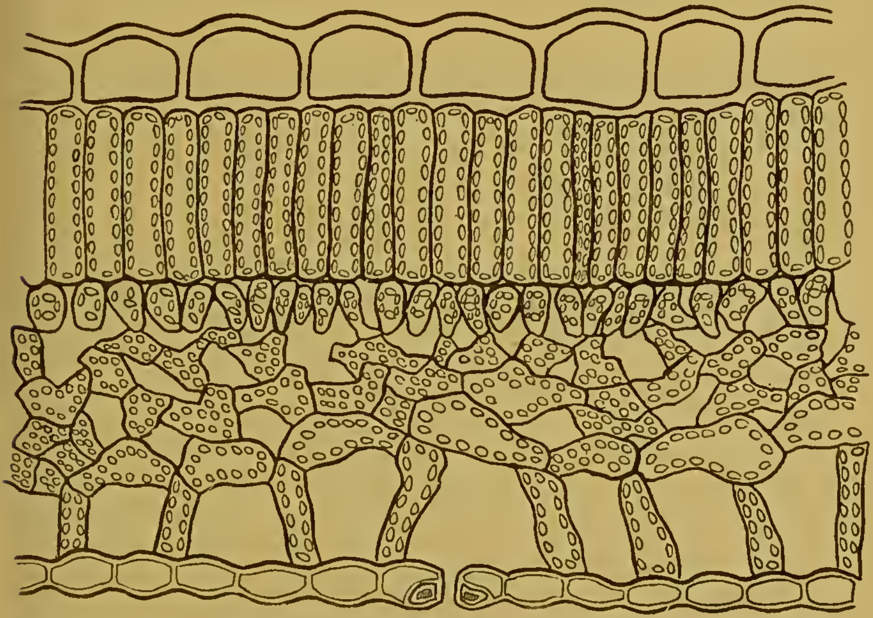

FIG. 29.—Cross-section through the leaf of a beech. Showing at the top the epidermis cells without chlorophyll, then the palisade layer with chlorophyll, then spongy layer with all the cells containing chlorophyll and with many air-spaces between the cells, lastly the epidermis of the under surface with a stoma. The chlorophyll corpuscles are the small oval bodies lying chiefly round the edges of the cells. (After Prantl and Vines.)

The spongy parenchyma is so called because of its spongy texture. This sponginess is due to the presence of a number of large intercellular spaces, which are formed by the irregular arrangement and form of the cells which compose the tissue. These cells are characterized by the large number of chlorophyll grains, or chloroplastids as they are sometimes called, which they contain. The large intercellular air-spaces allow the free circulation of air and gases among the cells of the spongy mesophyll. These spaces are in free communication with the external air, through the stomata which pierce the lower epidermis.

We must now consider the nature of the **chlorophyll grains,** or **chloroplastids** as they are sometimes called. In higher plants they are present as small definite corpuscles, usually rounded but occasionally angular. Like the chromatophores of *Spirogyra*, they consist of a protein substance impregnated with the green pigment. These chlorophyll granules are present in varying numbers. They are always embedded in the protoplasm of the cell. In the cells of some plants there are very many ; in the cells of others fewer, and it is in general true that in lower plants the chlorophyll corpuscles are fewer in number, larger, and less definitely shaped than they are in higher plants (Fig. 30). In the lower plants they may be stellate, latticed, plate-like, band-like, and in a few cases they

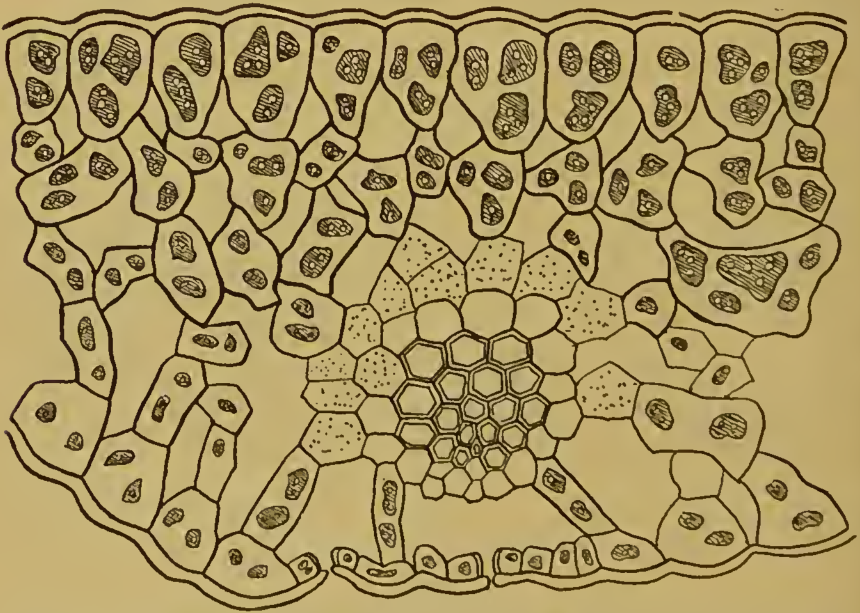

Fig. 30.—Cross-section through leaf of *Selaginella*, showing the epidermis containing chlorophyll, spongy parenchyma in the middle of which a fibro-vascular bundle has been cut through, and the epidermis of the under side with stomata. The chlorophyll bodies are large and irregular, and contain starch granules. (After Sachs.)

form hollow spheres. In *Spirogyra* they assume the shape of spirally wound bands (Fig. 8).

Chlorophyll corpuscles arise from colourless bodies **(leucoplastids)** present in young cells. When mature, they have the power of arranging and rearranging themselves in the cells they inhabit, under the stimulus of light. When kept in the dark for some time the green colour changes to yellow, and the corpuscles break up. The autumnal colours of leaves are due partly to changes of this kind.

The green pigment or chlorophyll plays a very important part in the life of all green plants. It is soluble in alcohol, ether, and chloroform. By transmitted light the solution is green, but by reflected light it appears blood-red. Chlorophyll appears to be an extremely unstable substance, and this fact renders the ascertainment of its chemical composition a matter of uncertainty. It does not contain iron as was previously thought, and when heated about 2 per cent. of ash is left behind containing magnesia, calcium, phosphoric and sulphuric acids.

Chlorophyll corpuscles possess the power of dividing and thus multiplying their numbers. In some cases they even change their form during their life.

The leaf is traversed by a number of branching veins or vascular bundles. In sections of the leaf these are seen to lie at the junction of the palisade layer with the spongy parenchyma. The xylem of the bundles lies uppermost, that is, faces the upper epidermis, while the phloem is beneath it.

Seen in section beneath the microscope the upper surface of a leaf may be distinguished from the lower by two points: first, the palisade layer is beneath the upper epidermis and the spongy parenchyma is within the lower; second, the position of the xylem in the vascular bundles indicates the position of the upper surface, which it faces.

The holly leaf is very similar in structure to that of the beech, but it differs from it chiefly in two features. First, beneath the epidermal layer, lying between it and the central mesophyll, is a layer of rather large squarish cells, called the

hypodermis. Second, the outer walls of the epidermal cells are chemically and physically modified to form an impervious substance called **cuticle.** This is present in most leaves, though in many it is extremely thin, as it is in the beech. But in the holly it is very thick, especially upon the upper surface of the leaf.

The formation of cuticle and its presence in plants which live under more or less dry and hot conditions, and its absence in aquatic plants, its strong development in evergreen leaves and its weaker development in deciduous leaves, or those which are annually replaced, is a striking illustration of the adaptation of a plant to its environment. All cells when they are first formed are covered with a thin and delicate cellulose wall. But in the course of development, those cells which are exposed to the surface undergo a modification in their outer walls. These become thickened and divided, as it were, into an inner cellulose portion, merging imperceptibly into an outer cuticular portion. In the cuticularized part the cellulose becomes altered and is replaced by a mixture of stearin and the glyceride of a fatty acid (suberic acid), forming a tallow-like fat called **suberin** or **cutin.** This fatty substance thus investing the whole surface of the leaf is impermeable to water and aqueous vapour. A leaf thus protected may be exposed to a dry, hot atmosphere without losing an undue quantity of its water, and is therefore protected against desiccation. A leaf devoid of cuticle is unable to survive a day's exposure to a dry, hot atmosphere, especially if the air is in motion.

When we say that the presence of this cuticle on plants exposed to dry conditions and its absence on those which live in a humid or aquatic habitat is an example of adaptation to the environment, the student must be careful not to allow any loose preconceptions which he may have acquired to induce him to wrongly interpret the statement. It should be clearly and definitely grasped that all adaptations are internal (gametic) and not external (somatic) in origin. They arise from innate qualities and not outward stimuli. They are congenital and belong to the characters of a race, and are not mere individual responses to capricious and varying external influences. We cannot, for instance, take a plant which is inherently adapted to a damp atmosphere, and by placing it in a dry one thereby cause it to become adapted to its changed circumstances. The mere presence of a dry atmosphere cannot by itself cause a cuticle to develop upon the leaves of a plant which belongs to a race congenitally incapable of forming it. That experiment has been tried again and again, and failed each time. In Vienna one such experiment was tried. A species of palm, *Caryota propinqua*, was grown in a greenhouse in the botanical gardens there, and it developed in the damp air a magnificent stem with large leaves. On a summer day, when the temperature of the open air coincided with that of the greenhouse, this *Caryota*, together with the tub in which it was rooted, was carried into the open and placed in a somewhat shady place, but partly exposed to the sun's heat. One day, after a warm, dry east wind had swept for only a short time over the foliage, it became quite brown, and in the evening all the leaves were entirely dried up and dead. Microscopical examination of the leaf showed that it possessed only a delicate epidermis without thickened walls, and within was a succulent tissue likewise with delicate and unthickened walls.

Mere change in environment does not change inherent structure by producing adaptive and related responsives in the somatic or body tissues. It may destroy an organism as it did the *Caryota*, but it cannot change it. And this is true whether the environmental influences operate for only a short period or extend throughout many generations.

That this is so is shown by the flora of the desert of Kaits, in Northern Ceylon. The plants of this region are the remainder of the flora of a previous period, when the soil and conditions had not become arid. The physical environment has changed in this district. But have the plants changed correspondingly? Examination of the commonest plants of the flora show that they have none of the qualities of desert plants. In direct contrast with ordinary desert types, they have a thin and delicate epidermis with exposed stomata; they are annuals, growing rapidly, blooming and ripening their seeds before the height of the dry season. Exposure to extreme conditions has not changed these plants in a desirable—that is adaptive—direction. During the many centuries that these plants must have existed in the desert in annual generations, no single feature in the anatomical structure has become changed.

And yet there remains the fact that organisms, both plant and animal, are to a greater or less degree, adapted to their surroundings. If the environment does not itself directly produce this adaptation, how then came it to exist? It came, because in Nature organisms are moulded to their environment, and not the environment changed to suit the needs of an organism's structure and capacities. The environment is there throughout long geological periods, relatively stable and having no regard of any sort to the deficiencies and weaknesses of the races exposed to its operations. If individuals are not inherently adapted to the conditions by which they are surrounded and from which they cannot escape, as was the *Caryota* to the climatic conditions of Vienna, then they perish, and with them the race which they represent. But if they are, then they survive.

The so-called adaptations which we see in Nature are the result not of adaptation in its strict and literal sense, but of elimination. Let us imagine a room having its walls, ceiling, and floor of a red colour and flooded with red light; into this room a procession of forms of different colours pass. If we further suppose that all the forms which are of the tint of red of the room itself remain, while all the forms of other colours pass out, there will remain in the room only the forms which have colour that harmonizes with their surroundings. Such forms are chromatically adapted to their colour environment. But there has been no adaptation in the literal sense, only a preservation or retention of things which conformed to the surroundings. The cardinal point to note is that this adaptation has not been reached by the alteration of every form which entered the room, but only by the retention of those which were already from their inherent nature in adaptation to the conditions.

Analogies nearly always carry within them latent dangers and stumbling-blocks. Such an analogy as we have given must be used with care. In Nature the environment is a complex of many factors acting continuously and simultaneously; it does not consist of a single factor. The organisms too are not characterized by one feature, but by many structural and physiological traits, acting not independently but dependent and correlated. Much complexity is thus introduced into problems of Natural Selection and Evolution. But still beneath the complexity lies the cardinal fact that the characters of an organism are inherent and depend upon what its race has hereditarily transmitted to it, and not upon any direct modification produced through environmental operations.

CHAPTER XVIII

THE STRUCTURE OF THE ROOT

IF we examine the root of a bean-plant we shall note that a little behind the extreme apex it is more opaque than the part immediately in front of it. The more transparent front part is the root-cap which covers the organic apex of the root. A little way behind the apical region the root is clothed with rather fine closely set hairs. Some way still further back the developing lateral rootlets which are arising from the tissues of the main root are to be seen. In some plants these are more or less regularly arranged in four vertical rows.

At the apical region of the root new tissues are being formed, and growth in length is occurring ; in this region, therefore, very little differentiated structure is seen. The root-hair region shows the primary structure of the young root, and behind this, where the lateral rootlets are coming forth, the root is undergoing secondary thickening owing to the formation of new tissues by the cambium. This cambium is not present, as a rule, in the root-hair region, though it is often developed in the region immediately behind.

In order to see the primary structure of the root, we must therefore examine sections across it in the root-hair region. Here the root is bounded externally by a membrane composed of a single layer of thin-walled cells (Fig. 31, pi). It corresponds to the epidermis of the stem. Many of its cells are prolonged outwards into unicellular hairs (r.h). These are called the root-hairs. They are essentially the absorptive tissue of the root, taking up the water with its dissolved mineral matters from the soil. On account of the development of the root-hairs from this outer investing membrane, it is called the **piliferous layer.**

Within the epidermis is the **cortex** (cor). In roots this is

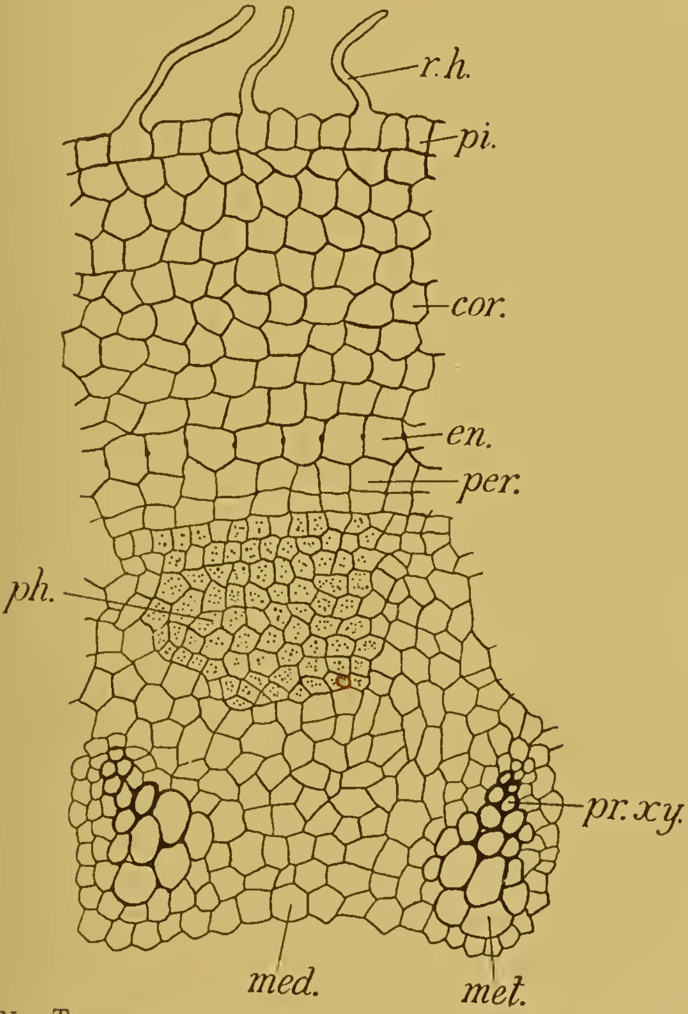

FIG. 31.—Transverse section of a root; a portion only, including two rimary xylem strands and one phloem. **cor.** Cortex. **en.** Endodermis. er. Pericycle. **ph.** Primary phloem. **pi.** Piliferous layer. **pr.xy.** Protoxylem. ed. Medulla or pith. **met.** Metaxylem. **r.h.** Rhizoid or root hair.

elatively very wide. It is composed of several layers of hin-walled parenchyma. Its innermost layer (en) consists of ells rather larger than the rest and characterized by the presence of an apparent dot-like thickening on the radial wall of the cells. It is, however, only apparently a thickening, and is due to a delicate undulation of the radial wall. The light from the microscope mirror is reflected from the bends of these undulations, and produces therefore the optical appearance of a dark spot.

The **pericycle** (per), which in the root, as in the stem, lies immediately within the endodermis, is, for the most part, and in most roots, a single-layered membrane. But in the bean root, opposite the phloem strands, it tends to be composed of two layers of cells. The pericycle in the root thus differs from the same sheath in the stem, for it is there multilayered.

Within the pericycle are the vascular tissues which lie embedded in the fundamental tissue or, as it is specifically called, the intra-stelar ground tissue. In this portion of the root, where it is still young, the vascular tissues are all primary, that is, derived from the apical meristem or the genetic tissue at the apex of the root. As in the stem, so in the root, the vascular tissues are composed of xylem and phloem and a certain amount of parenchyma. But their arrangement is different. Instead of lying on the same radii, the phloem immediately outside the xylem, they lie on alternating radii. The phloem strands lie somewhat more distally from the centre than the xylem. This alternate arrangement must be indicated by some definite term; and while we speak of the type of bundle in the stem as **collateral,** that in the root is termed **radial.**

There is a further difference which distinguishes the primary vascular tissues of the root and stem. In the latter the lignification of the xylem elements begins at the central part and proceeds outwards towards the periphery. In the root it is the other way round. In the former case we speak of a **centrifugal development** of the primary xylem, and in the latter of a **centripetal development.** The proto-xylem (pr.xy) of the root, like that of the stem, consists of spirally and annularly thickened vessels. Pitted vessels are absent. They are present in the metaxylem (met). The primary phloem is similar in composition to that of the stem.

Apical Development

Both stem and root grow in length by the addition of new tissue which is developed at the apex of the organ. In some cases there is situated at the apex of stem or root a little mass of rapidly dividing cells. They are undifferentiated, except their outermost layer, and are characterized by their abundant protoplasm, relatively large nucleus, absence of a vacuole, and extremely thin delicate cell-walls. From this undifferentiated **apical meristem** are derived a genetic **dermatogen** begetting the epidermis. Behind this there is a **periblem** giving rise to the cortex and a central **plerome** from which the central stele and its vascular tissues are derived.

In most stems, however, the apical meristem is itself differentiated into these three layers, so that we can trace the epidermis upwards to a single-layered dermatogen covering the apex of the stem, and the cortex to a single-layered periblem lying within the dermatogen at the apex, and the vascular stele to single-layered plerome immediately beneath. The cells of the dermatogen divide only by walls at right angles to the surface of the stem, those of the periblem by parallel walls in addition, and those of the plerome in all directions.

In the root the meristematic layers are also present at the apex, but in addition there invests the organic apex of the root a little mass of cells which fits over it like a cap. This is called the **root-cap,** and it is derived from a special meristematic layer called the **calyptrogen.** This gives rise to both the piliferous layer and the root-cap. Its cells divide alike by walls at right angles, and parallel to the surface. The outer cells which are formed by the parallel divisions go to form the root-cap, and those which lie within, and only subsequently divide by right-angled walls, produce the piliferous layer, which thus remains one cell thick.

CHAPTER XIX

STRUCTURE OF ANIMAL CELLS

WE have found that the simplest organisms, whether they belong to the animal kingdom or to the plant kingdom, consist of single cells. The bodies of all higher animals and plants are made up of many cells which are the result of cell-growth and cell-division. In a sense, then, cells are the **units,** the living bricks out of which the animal and plant body are built up. We have seen, however, that, as in *Amœba*, *Paramœcium*, *Monocystis*, *Vorticella*, and *Protococcus*, very many different structures, which one may call organs, are present within the cell, and that different cells assume very different shapes and appearances and have very different properties. In the body of the plant we saw how the different tissues were made up of cells specialized for different purposes. So also in the animal body each tissue and organ has cells of special structure and with special functions. In Fig. 32 there are represented three of the many types of animal cells taken from a frog. At *a* is an epithelial cell taken from the roof of the mouth. The surface of the cell that is exposed to the cavity of the mouth is covered by cilia, which serve to sweep currents of water and mucus along the mouth. At *b* is a cell from the wall of the intestine drawn during a period of activity; the end turned towards the cavity of the gut has pseudopodia by which food particles are ingested from the intestine ; some of these appear within the protoplasm. At *c* is an unstriated muscle cell from the bladder.

Now these cells are typical of the kind of cell-specialization which occurs. Each of them is modified and adapted to serve the animal, the cell-community of which it forms a part, in some particular direction. But in addition each performs all the functions of protoplasm on its own account. Each takes in oxygen and discharges carbonic acid, takes in food materials and discharges nitrogenous waste; each grows when there is a balance of income from food over expenditure, and at least in the earlier period of its life, though seldom after it is specialized, each is capable of reproduction by simple division.

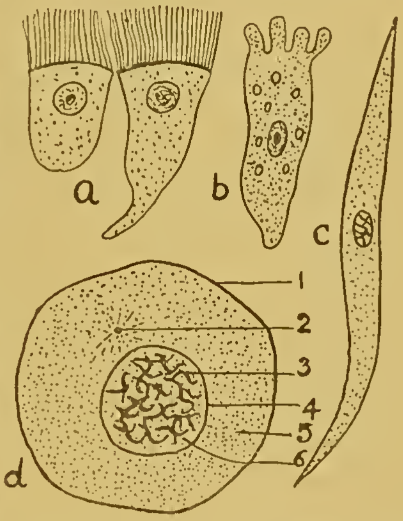

FIG. 32.—**a.** Two ciliated cells from roof of mouth of frog. **b.** Cell from wall of frog's intestine with food vacuoles and pseudopodia. **c.** Unstriped muscle cell from bladder of frog. **d.** Diagram of cell.—**1.** Cell-wall. **2.** Centrosome. **3.** Chromatin lodged in linin fibres of nucleus. **4.** Nuclear membrane. **5.** Cytoplasm of cell-body. **6.** Nuclear sap.

Overlooking the peculiarities of the different kinds of cells, it is necessary that a clear idea of the general structure of every cell should be attained (Fig. 32, *d*). The protoplasm of the cell consists of two distinguishable parts. There is what appears under the highest powers of the microscope a network or meshwork extending all through the body of the cell. This is so exceedingly fine that the meshes convey the appearance of granules or fibres of more solid material (*see* Figs. 3 and 4), but there is reason to believe that it consists not of a network of more solid material, but of quite fluid material, forming the walls of the bubbles of a very delicate foam. Occupying the bubbles, or, as it is more generally described, bathing the meshes of the network, is a fluid juice containing probably the dissolved nutritive materials and the waste products of the protoplasmic activity. Under the ordinary powers of the microscope, all that can be seen is a more or less clear or granular protoplasm. This, which forms the body of the cell, may be called the **cytoplasm** or **cell-protoplasm.** The cell-wall, when present, is usually only a surface film and may theoretically be regarded as consisting in the first place of more regularly arranged bubbles of the foam or meshes of the network, but strengthened by deposits of a secretion formed by the protoplasm of the cell. Within the cell lies the **nucleus,** composed at certain times of a network and a fluid bathing the network. The substance of the network may be called **linin,** and the fluid part the **nuclear sap.** The nucleus is surrounded by a delicate **nuclear membrane.** All the substances within the nucleus may collectively be called the **nucleoplasm,** to distinguish it from the cytoplasm. The parts of the cell which we have described absorb stains or dyes rather feebly, and, when a stained cell is placed in a solution containing a solvent of the stain, the greater part of the colouring is removed. But, as we have seen already, there is within the nucleus another substance, existing in a granular form, and which absorbs staining materials with greater avidity, and which combines with the stains so firmly that when placed in a solvent very little is given up. This part of the nucleus, on account of this property, is named **chromatin,** and most are agreed that the chromatin is the part of the nucleus which is the bearer of its special properties. In most stained nuclei these chromatic elements appear as little separate granules or pieces very much larger than the granules of the cell-protoplasm. They may be called the **chromomeres.** In addition to these, there is present in the nucleus of many cells a large spot, that in the case of egg cells has been called the **germinal spot.** In the somatic or body cells, it is called the **nucleolus.** It is composed of clearer material, and though its function has not been made out with certainty, it has been seen to contract and expand slowly, each set of movements occupying several hours. It is therefore supposed by some to be a special pulsating vacuole for the nucleus, an excretory organ usually inactive, but coming into use when the cell is going through active changes like the changes of division. It may, however, be a store of reserve food material, to supply energy to the nucleus during cell-division.

Lastly, there has been shown to be present in some cells during their inactive condition, and in very many cells while they are undergoing a complicated process of division, a very small body composed of a material that stains only when special methods are applied to it. This is termed the **centrosome** (Fig. 32, *d* 2) because in the process of division it is the central body of a small circular area named the **directive sphere,** formed by the protoplasmic granules arranging themselves like radiating beams round the centrosome. It has been suggested that this is present in every cell, but that, owing to its minute size and the difficulty of staining, it can seldom be seen until, in the process of division, the rays of granules arrange themselves round it.

CHAPTER XX

THE MULTICELLULAR ANIMALS OR METAZOA

THE DIPLOBLASTIC ACŒLOMATA

Hydra, the Freshwater Polype

THE whole animal kingdom is divided into two great groups. The first of these is called the **Protozoa.** To it belong *Amœba*, *Vorticella*, *Paramœcium*, and *Monocystis*, and all animals the bodies of which consist of a single cell. Occasionally among Protozoa, when reproduction takes place the new individuals do not separate from each other, but build up a **colonial form.** Such colonies of Protozoa may consist of a definite number of individuals : the whole colony may have a definite shape and in some few cases even all the individuals may not be exactly alike. But it never happens that the individual cells of a colony are arranged and specialized so as to form tissues and organs. All animals with bodies composed of cells arranged in definite layers and tissues which serve a special purpose in the economy of the whole animal, belong to the second and higher division of the animal kingdom and are called **Metazoa.** After the examination of one metazoon we shall extend and make more definite our idea of the nature of this group and of its points of contrast with the Protozoa.

The first metazoon that we shall examine is a small freshwater animal called *Hydra*. Three species of it are not uncommon in the ponds and ditches of this country. The largest specimens are, when fully extended, about three-quarters of an inch long ; the smallest are easily visible to the naked eye. *Hydra viridis*, the green hydra, owes its colour to the presence of a large number of unicellular algæ, in the inner layer of its body-wall. *Hydra fusca* is brown or yellow and *Hydra vulgaris* is nearly colourless. Apart from these colour differences the species are very similar, and any one will serve equally for examination. The specimens should be examined in the living condition, in a watch-glass containing water placed under the low power of the microscope. They consist of a cylindrical body attached to a piece of weed or to the side of the glass at one end. At the other end there is a circle of from six to ten long slender thread-like processes (Fig. 33). These are the **tentacles,** and they surround a small rounded elevation called the **hypostome,** at the free end of the cylindrical body, with a circular opening, **the mouth,** at its summit. The whole body is exceedingly contractile. A slight touch with a needle will make a fully extended specimen contract almost at once to a little lump with the tentacles as thick knobs. By careful manipulation with needles or with a camel's hair brush, a specimen may be detached from its support. When it has recovered from the shock, it may be seen creeping along the bottom of the glass supported by its tentacles and carrying uppermost the **pedal disc** by which it was attached. Or it may creep by a series of looping movements, fixing itself by the pedal disc and stretching out the body so that the tentacles may attach themselves to a point some distance off, when the pedal disc loosens its hold and by contraction of the body is pulled to a fresh place for attachment, nearer the tentacles. Such movements are, however, of infrequent occurrence if the *Hydra* be undisturbed.

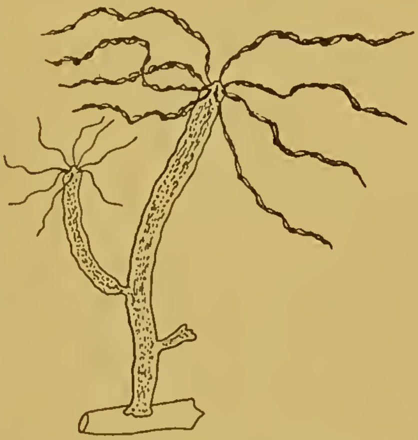

FIG. 33.—*Hydra vulgaris* in expanded condition; to the left is a young Hydra which has budded out from the larger specimen; to the right is a young bud.

The water in which *Hydra* is found contains a number of small water fleas, and if some of these be placed in the watch-glass with it, before long one of them is certain to swim up against a tentacle. When this happens the motions of the flea are suddenly arrested : it has been not only caught but paralysed by some poison, and the *Hydra*, by bending the tentacle, draws it in towards the mouth and, sometimes with the aid of other tentacles, pushes it through the mouth into a central cavity. If *Hydra* be watched for some time, it may be seen to discharge from the mouth parts of the shell and other *débris*, the indigestible remains of similar fleas it has captured before. Thus the mouth serves also as an anus.

To study *Hydra* more fully, a single specimen should be removed to a slide in a small drop of water and covered with a glass-slip. Care should be taken not to let the slip drop too suddenly upon the animal, as its delicate structure is easily broken up and destroyed. If the *Hydra* is not sufficiently compressed, some of the water may be removed by a piece of blotting paper applied between the edge of the cover-slip and the glass. When this has been done, observation with a higher power is possible. If the specimen be a green or a brown *Hydra*, it will be at once apparent that the body and the tentacles are composed of two layers. The outer layer is thinner and is quite colourless and transparent : the inner layer is deeply coloured by small granules, which in the case of the green *Hydra* are chlorophyll-containing bodies believed to be unicellular algæ, and in the brown *Hydra* are granules coloured by a substance closely allied to chlorophyll. The central region of the body is a cylindrical cavity, and into this cavity, which is called the **enteron,** the mouth opens. In a living specimen the enteron appears as a darker region in which occasionally the bodies of captured water fleas may be seen. Each tentacle is hollow, but, in the living condition, it is almost impossible to see either the hollow or its opening to the enteron. In this condition it is easy to see that the outer surface of the tentacles is studded with little knobs. Here and there upon the knobs delicate projecting bristles may be seen, and if the *Hydra* has been irritated, exceedingly long pointed threads may be seen protruding. These threads are the poisoned lassoes by which *Hydra* catches and paralyses its prey. They are too delicate to pierce the human skin: but in some tropical sea-anemones and in jelly-fish of our own coasts such nettle cells or **nematocysts** are present, and are strong enough to cause considerable pain, and sometimes poisonous enough to produce disagreeable effects if the naked skin of man come in contact with them. In *Hydra* the nettle cells are most numerous on the tentacles, but they occur also on the whole outer surface of the body. By focusing carefully they may be seen as small oval bodies, rather more pointed at the outer end and of a greenish yellow colour. Some of them lie close to the surface, and in these a small bristle, the **trigger-hair,** or cnidocil, protrudes beyond the surface of the animal. When this is touched by an external object, the lasso is shot out with great force. Before it has been discharged it lies coiled up within the nematocyst, and with an ordinary student's microscope at least the beginning of the coil may be seen. Fig. 34 represents very greatly magnified views of nematocysts isolated by pressure upon the cover-slip from the general surface of the body. An undischarged cell consists of a large rounded parent cell called the **cnidoblast**, with protoplasm, a nucleus, and the protruding trigger-hair or cnidocil. Embedded in the protoplasm is the mechanism of the lasso. It consists of an elongated tough sac, the nematocyst, one end of which is tucked into the larger end,

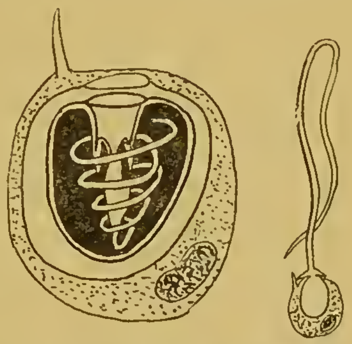

FIG. 34.—To the left is an enlarged diagrammatic view of an undischarged Nematocyst embedded in a nucleated cell. The granular body with the nucleus is the nettling cell or cnidoblast. The white space represents the wall of the nettling organ or nematocyst. Within it can be seen its neck and coiled stinging-thread. The bristle-like process on the left-top of the cell is the trigger hair or cnidocil. To the right is a discharged nematocyst.

like the finger of a glove turned outside in. The point of this infolded part is continued into a long, very delicate thread, which also is hollow. The whole space between the wall of the sac and the inturned part and the thread is occupied by a fluid under considerable pressure. When any additional pressure from the outside is brought to bear on the sac the apparatus suddenly goes off: the inturned part of the sac is first turned, or forced out, and then the long thread follows it, both being turned inside out in the process. The second drawing shows a nematocyst shot out in this way. It has barbs at the root of the thread, an addition that is not present in all the nematocysts of *Hydra*. A thread cell once discharged cannot be used again. There are, therefore, a considerable crop of them always growing, and smaller partly formed thread cells may be seen in the inner part of the outer layer of the body. Processes from the nerve cells have been traced into the protoplasm of the cnidoblast. The discharge of the lasso is caused by contraction of this protoplasm under the influence of a nervous excitation.

Among the specimens of *Hydra* collected at any time, some are likely to exhibit the results of multiplication by budding. In Summer, while food is abundant and the weather warm, tiny hollow buds grow out from any region of the wall. The hollow of the buds is continuous with the enteron at first, although when the bud has grown longer this connexion ceases. At the other end of the bud a mouth-opening appears and the circle of tentacles grows out (Fig. 33). Sometimes on the same *Hydra* several buds may be seen, and even on these buds other buds may grow out, so that the whole forms a temporary branching, compound animal made up of many individuals. Each of these, however, is practically a separate animal, and may break off or be removed artificially and live an independent life.

If the specimens be collected from ponds towards the end of summer, or if they be kept in captivity and starved for a few days, sexual reproduction occurs. In some individuals, on the body-wall near the base of the tentacles one or two small lumps appear. These are the **testes,** or male reproductive organs, and from them the **spermatozoa**, or male sexual cells, are shed into the water. The same specimen of *Hydra* may produce the female sexual organ, but this hardly ever is to be seen on a *Hydra* at the same time as it produces the testes. As we know from observation of higher animals, one of the advantages of sexual reproduction is that the progeny may be, under certain circumstances, probably more hardy when the parents are not closely related. In *Hydra* and in other animals in which the same individual produces both male and female organs, the benefits of crossing would probably be missed if the female cell was ripe at the same time as male cells were being discharged near it from the same animal, and in correlation with this it is seldom the case that one individual has the organs of both sexes at the same time.

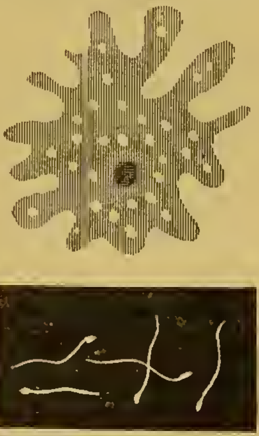

Fig. 35.—Ovum of *Hydra* with pseudopodia, nucleus, and yolk-spheres; the latter appearing as white spots. Below is a group of spermatozoa showing the enlarged head containing the nucleus.

The female organ or **ovary** of *Hydra* is always single, and is produced from the body-wall much lower down than the testes (Fig. 36). As a rule it contains only one egg, and is a large and conspicuous organ. The ovary at first consists of a mass of tiny cells. But one of these sends out pseudopodia among the rest, and gradually eats them up until it becomes very large. In this condition it appears like a huge amœba (Fig. 35), and contains embedded in the protoplasm a number of small yolk granules, which are reserve stores of protein matter formed by its protoplasm. When fully grown the pseudopodia are withdrawn, and the egg-cell is spherical. As it has been eating up the small cells which lay around it, a part of its surface is bare and protrudes beyond the surface of the *Hydra*. The male cells, or spermatozoa, which were discharged into the water, each consists of a nucleus, which forms the **head** of the spermatozoan, and of a small body of protoplasm, the most of which projects behind the nucleus as a long tail. By the vibrations of these tails the spermatozoa are driven through the water. If one of them reaches the exposed surface of the egg on a *Hydra* it conjugates with that. The tail is retracted, while the head, or nucleus, and a small fragment of protoplasm enter the egg-cell. The incoming spermatozoon-nucleus then fuses with the nucleus of the egg-cell and fertilization is complete. Soon afterwards the fertilized egg-cell begins to divide. From the resulting cells a cap or wall of cells, each with thick cell-walls, is formed. The egg so protected falls out of the *Hydra* and sinks to the mud at the bottom of the pool. In this condition it remains throughout winter. In spring, when the water is warmer, it develops into a new *Hydra* in a way that will occupy our attention later on.

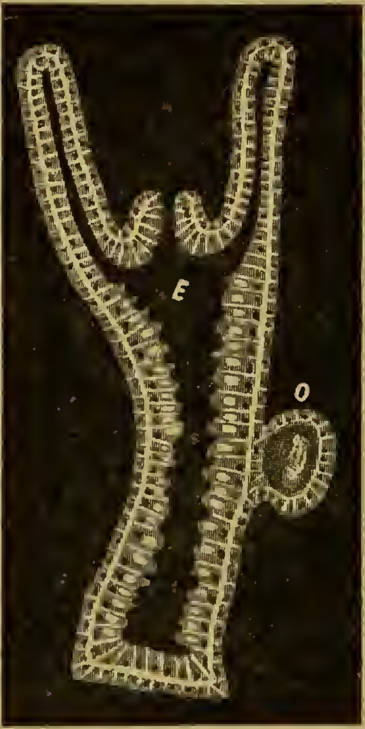

FIG. 36.—*Hydra*: diagrammatic longitudinal section passing through two tentacles, the mouth and an ovary, **O**. **E**. The enteron or primitive digestive cavity continuous with the tentacle cavities and opening to the exterior by the mouth. The body-wall consists of two layers separated by the mesoglœa, here shown as a white line.

Further study of *Hydra* is best made by the examination of excessively thin slices. As the preparation of these is a matter requiring great practice, the elementary student should content himself with the study of sections already prepared. Of these there should be examined a longitudinal section (Fig. 36) and a transverse section more highly magnified and taken through the cylindrical body (Fig. 37). The longitudinal section is a thin slice cut lengthwise out of the middle of the whole animal. It passes through two tentacles, through the hypostome and mouth, and through the enteron and the body-wall. It may be seen at once that the whole animal consists of a hollow sac surrounded by two layers of cells. Of these the outer layer, or **ectoderm,** is thinner, and among its cells are contained numerous thread cells. The inner layer, or endoderm, is thicker, and its cells, where they line the enteron, have irregular surfaces, from which cilia and pseudopodia project into the enteric cavity. In these, in *Hydra viridis*, are seen embedded numerous chlorophyll corpuscles, or unicellular algæ, and thus the endoderm is very clearly marked off from the ectoderm. But in all *Hydras* it may be seen that between the two layers is a narrow band of a fibrous nature. This is composed, not of cells, but of a gelatinous secretion, into which fibres from the cells of both the ectoderm and the endoderm run. It is termed the **mesoglœa,** or middle jelly, and is a skeletal structure of little importance in *Hydra*.

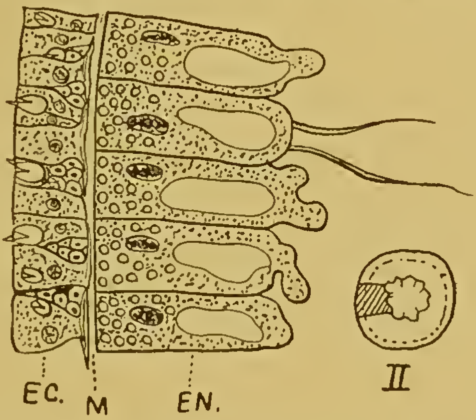

FIG. 37.—*Hydra:* part of a transverse section much magnified. **EC.** Ectoderm with protective cells, muscle cells, nematocysts and interstitial cells. **M.** Mesoglœa. **EN.** Endoderm: each cell has a large nucleus and a vacuole, and either pseudopodia or flagella projecting into the cavity of the enteron. They also contain numerous small chlorophyll bodies. The shaded area in the small circle at **II.** shows the part of the transverse section taken.

In the more magnified transverse section the structures present are more plainly represented (Fig. 37). The ectoderm consists of several kinds of cells. There are the **ectoderm** or **covering cells,** the surface of which is exposed, and the more contracted bases of which reach the supporting mesoglœa. The narrowed bases are continued into pointed neuro-muscular processes, lying at right angles to the cells themselves, and parallel to the long axis of the body. These processes are almost certainly muscular in nature, and very probably they are connected with fine filaments which come off from underlying nerve cells. Lying between the covering cells are the fully formed thread cells. In the angular spaces between the contracted bases of the covering cells are placed the **interstitial cells,** which are small and irregular; they give rise to the cell masses which form the testes and the ovary, and among them are numerous young thread cells; the protoplasm of these cells is fused with that of similar adjacent cells, and there is thus formed a particular kind of tissue called a **syncytium.** Beneath the ectoderm cells and lying upon the mesoglœa, we find large **ganglion** or nerve cells, which do not reach the outer surface; each possesses a large nucleus and numerous branching protoplasmic processes, but these cannot be seen except in macerated preparations; they are in connection with the thread cells, and in some cases with the muscle processes of the ectoderm cells. At the pedal disc there are some large cells with clear contents which form a sticky secretion by which the animal clings to the surface to which it is applied.

The **endoderm cells** are very large, except in the region of the hypostome, where they form granular secreting cells. Those lining the greater part of the enteron possess large vacuoles containing a digestive fluid, which is periodically discharged into the enteron, and fresh is subsequently formed in the cell. They may have two or three long cilia or flagella, or they may have active pseudopodia. Within them are to be seen food vacuoles, containing particles of food material taken from the enteron by the pseudopodia. They also contain the green unicellular algæ.

Even in sections, the cells are so closely packed together that it is impossible to see all the details of their structure. For this purpose a living specimen should be placed in water containing a drop of acetic acid and a drop of osmic acid, and after a few minutes removed for several hours to a 0·2 per cent. solution of acetic acid in water. After this the specimen should be stained with picrocarmine solution. This course has the effect of hardening the cells and of rendering them easy to separate from each other. Small pieces of the *Hydra* should be placed on a slide in a drop of 50 per cent. glycerine and teased with needles. A few sharp taps with the point of a needle on the top of the cover-slip will assist the process of separation, and it will be found that many of the cells are completely isolated or adhere in little groups, so that with trouble the different kinds of cells may be picked out.

Let us now consider *Hydra* as a living organism. In the first place, it is composed of many cells of different kinds, and these are arranged in a definite way, so that the body consists of a hollow sac, the walls of which are composed of two distinct layers. The cells, however, are not, as in plants, surrounded and separated from each other by cell-walls. In the living condition it is only in a few cases that the cell outlines are visible: but when the protoplasm has been set and slightly shrunk by the action of reagents, the limits of the individual cells become apparent. The whole animal forms a mass of protoplasm so continuous that, without the aid of the blood-vessels and nerves of higher animals, every part is in organic connexion with every other part, and the characters of the whole *Hydra* are a result of the combination of the cells. In the case of a colony of Protozoa, some of the cells may be injured or influenced without the influence being transferred to the whole colony, and certainly without the cells of the colony, by their combined action, responding to the stimulus. If a water flea comes in contact with the tentacle of a *Hydra*, the muscle cells of that tentacle begin to contract, so that the prey is drawn down towards the mouth. But other tentacles may also contract in such a definite way that they assist in the process of swallowing. Again, if the tentacles, or one of them, be touched with a foreign object, as, for instance, a needle, the whole *Hydra* suddenly contracts, and this is the result of the contractions of the muscle cells all down the tentacles and body. When the animal creeps about, the motion is due to the concerted action of many separate muscle cells contracting at the same time in different ways. In higher animals such co-ordination is effected, or at least assisted, by definite chains of nerve cells and nerve fibres connected with each other and with muscles and sense-organs. It is almost certain that in *Hydra* the nervous cells are not arranged with sufficient definiteness and regularity to be the chief agent. Most probably they are chiefly of local use and act in concert with the thread cells and neuro-muscular fibres. But the combination of all the cells to form an individual is seen clearly in other functions, where the nerve cells certainly do not come into special operation.

All the cells of the body require nutritive material. But the functions of digestion are performed only by the endoderm cells for the whole organism. When food is taken into the enteron, digestive juices are poured on it from some of the endoderm cells, chiefly perhaps from the granular cells lining the hypostome. The other endoderm cells ingest the food particles in the enteron, and hand on nutritive materials to the ectoderm cells. Again, the function of sexual reproduction is undertaken for the whole *Hydra* by the few cells that form the ovary and the testis ; but, however independent these may appear, their formation appears to be stimulated by starvation of the whole organism. The extent to which the individuality of the whole organism is stamped upon the separate cells is seen in budding. The bud is formed by a projection containing endoderm, mesoglœa, and ectoderm ; but it may grow out from any part of the body, and yet ultimately will reproduce the tentacles, the pedal disc, and the whole organism. Similarly, when a *Hydra* is cut across, from the cut end of the upper half, the lower part of a new *Hydra* grows out, while from the cut end of the lower half the cells required to complete the upper half grow out.

It is this co-operation of all the cells, this co-ordination by which the cells lose part of their own individuality in the new individuality of the whole animal, that is the great distinction between the Protozoa and the Metazoa. In higher forms of Metazoa, much of the interaction of the parts of the whole organism depends upon the existence of organs and systems common to the different parts—as, for instance, the nerves and the blood-vessels. But even in such higher animals there are many relations between the cells and organs which cannot be explained by the existence of sets of connecting organs; and it is of importance to remember that, beginning with the simplest Metazoa, the cells and organs are living, co-operating parts of a living whole.

As we have seen, the food is of the kind that, in a previous chapter, we found to be characteristic of animals. When green algæ or chlorophyll bodies are present in the endoderm cells, these no doubt contribute to the food supply of their host, as they, like all chlorophyll bodies, cause the elaboration of starch from carbon dioxide and water, and the oxygen liberated in the process may serve the respiratory purposes of the *Hydra* cells. If these green bodies are separate plants living in *Hydra*, they are to be regarded, not as parasites, but as instances of the association of different organisms for the advantage of each. This kind of association is named **symbiosis.** In **parasitism** the parasites live at the expense of their hosts; in symbiosis both the host and the guest derive advantage from the association. In this case the plant cells are protected by their position within the *Hydra*, and they obtain the carbon dioxide which is one of their food constituents, and which the animal gives off as waste, while the animal cells get both oxygen and perhaps sugar derived from the starch manufactured by the plants.

Apart from such a special source of oxygen, the cells of *Hydra* obtain their supply of oxygen from air dissolved in the water. Most probably each cell takes in its own supply and in turn discharges carbon dioxide. In the same way it is probable that each cell directly discharges its own waste products into the water, although contractile vacuoles have not been observed.

We have yet to consider the development of a new *Hydra* from the fertilized egg-cell (Fig. 38). While it still remains in the tissues of the mother, the egg-cell divides in two ; then each of these again divides, and after a number of divisions a little hollow sphere of cells termed the **blastula** is formed. The wall of the blastula at first consists of one layer of cells, but by the division of these cells an outer layer is produced. These have thick walls, and form a protective coat surrounding the egg when it drops from the ectoderm of the parent into the mud. The inner layer, which is the real embryo, is not perfectly regular. The cells at one end are larger and contain more yolk particles. When the further development takes place, the cells with the larger supply of food-yolk multiply rapidly, and the cells so formed from them get pushed into the hollow of the blastula. When this has taken place the outer protective coat ruptures, and the young larva is liberated. By rapid division of all the cells it grows larger, and the cells in the middle, instead of occupying all the space, become arranged round a central cavity—the enteron : the cells which migrated inwards from one pole form the endoderm, and the outer layer is the beginning of the ectoderm. The embryo grows longer. A gelatinous layer,

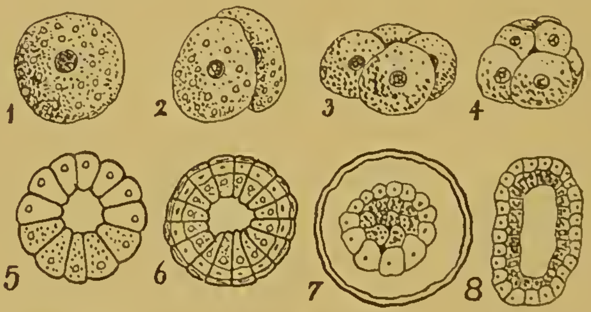

FIG. 38.—Diagram of development of *Hydra*. 1. Egg-cell fertilized and ready to divide. 2. Division into two. 3. Division into four. 4. Division into mulberry mass of which the lower cells are larger. 5. Section through blastosphere or blastula. 6. Formation of protective case. 7. Section through later stage ; the embryo lies within the case, which no longer shows its cellular structure ; the larger cells at the lower end have multiplied rapidly and fill the interior. 8. The inner cells are arranged in a single layer so that the embryo is a two-walled hollow mass. In this condition it corresponds to a gastrula.

the mesoglœa, is deposited between ectoderm and endoderm. A mouth aperture breaks through at one end, and round this the tentacles grow out as little buds. While these changes in shape take place, the cells, at first all much alike, become specialized into the adult condition.

Let us now sum up what we have learned with regard to the classification of the animal kingdom.

It is divided into two great groups, the **Protozoa** and the **Metazoa.**

The group **Protozoa** consists of all animals which throughout their lives are single cells, or which, if by cell division they form colonies, do not have the cells of the colony arranged and specialized to form definite tissues.

The group **Metazoa** consists of all multicellular animals which have the following characters :—

1. The cells are specialized and arranged to form definite tissues. Among these, except in the case of a few degenerate animals, there always are :—

(A) An outer layer or **ectoderm.**

(B) An inner layer or **endoderm** which surrounds an **enteron** or central digestive cavity.

2. The individuality of the separate cells is subordinated to, and influenced by, the individuality of the whole animal.

3. Sexual reproduction always occurs. There may be a series of generations produced asexually, as, for instance, by budding, but eventually sexual reproduction sets in. This takes place by fusion of a male cell, or spermatozoon, with a female cell, or ovum, formed respectively in male organs or testes and female organs or ovaries.

CHAPTER XXI

THE GASTRULA, CŒLENTERATA, AND CŒLOMATA

AS the Protozoa are all small animals, and most of them invisible to the naked eye, it is plain that by far the majority of animals, the appearance of which is familiar to us, belong to the Metazoa. Among the Metazoa, for instance, are man himself and the quadrupeds, birds and reptiles, frogs and fishes, snails and cuttle-fish, insects and creatures like water-fleas and crabs and lobsters, worms and star-fish, and the host of soft, gelatinous animals like jelly-fish and sea-anemones, as well as their allies with hard skeletons such as corals. In all this variety of animal life there are many sets of animals which naturally fall into groups, and the science of Zoology occupies itself largely with the investigation of the characters of these groups, and with the relations between them. Just as the whole Animal Kingdom falls naturally into two great groups, so also the Metazoa themselves belong to two distinct types, **Cœlenterata** and **Cœlomata.** To the former or lower of these **Hydra,** and a number of branched forms very similar to it, the medusæ or jelly-fish, and the sea-anemones and corals, belong. These differ in the shape and size of the body, and especially in the shape and arrangement of the enteron, in the number and arrangement of the tentacles, in the nature of the cells and the tissues, and in many other respects. But all of them are united by one great character; their bodies consist of a wall made up of ectoderm, mesoglœa, and endoderm, and this surrounds a single central cavity—the **enteron.** As the mesoglœa or middle lamella is not composed of cells, but of a structureless jelly, and so does not rank as a special layer, the cœlenterata are frequently termed **Diploblastica,** or the two-layered animals. The typical cœlenterate structure is in fact a little hollow sac or stomach with a mouth at one end, and with a wall composed of ectoderm and endoderm. No animal actually so simple as this is known, but a stage like this occurs in the development of many Cœlenterata as well as of many of the higher group, the Cœlomata, and it is probable that all the Cœlomata sprang from a simple Cœlenterate such as this. Let us try to form a picture of such a free living stomach or **gastrula,** as it is called, and of the changes in it which would lead up to the structure of higher animals. In Fig. 39, I, is represented a gastrula cut through the middle of the mouth, or as it is technically called, the **blastopore,** and down through the middle of the body, so as to show the ectoderm and the endoderm. We know from study of existing Cœlenterates that at least three kinds of cells would appear in the ectoderm, simple protective cells (II *a*), nerve cells (II *b*), and muscle cells with long contractile muscle fibres (II *c*). The protective cells remain as an external layer. We know that the nerve cells move inwards and form a network of ganglion cells underlying the external layer, while the muscle cells move still further in, so that they form a layer of fibres wrapping round the gastrula under the nervous layer, with a nucleus on each fibre to represent the original cell (Fig. 39, III). The nervous layer remains between the outer cells and the muscle fibres, and so is able to register impressions or stimuli received from outside by the external cells, and

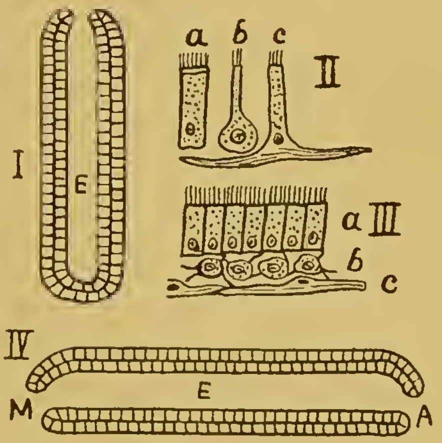

FIG. 39.—I. Diagram of gastrula. **E.** Enteron. **II.** and **I.** Enlarged diagram of ectoderm cells. **a.** Protective; **b.** nervous; **c.** muscular; at **II.** all three reach the outer surface; at **III.** the nerve cells have migrated inwards to form a layer under the protective cells, and the muscle cells form a similar layer still more internal. **IV.** Diagram of elongate gastrula with—**M.** mouth; **E.** enteron; **A.** anus.

to transmit the stimuli to the muscle fibres as messages to contract. In some Cœlenterates a similar set of nerve cells and muscle cells separate themselves from the endoderm and lie as in the first case with the muscle fibres nearest the mesoglœa. Between the two layers of muscle fibres formed in this way, there may be a small or large amount of mesoglœa deposited.

The first change that we may suppose to occur in such a gastrula is a considerable elongation, so that the mouth lies at one end of a long oval body. Then at the opposite end from the mouth another aperture into the enteron appears. The animal is now an elongated cylinder with a mouth at one end and an anus at the other (Fig. 39, IV). The food is taken in by the mouth, passed into the alimentary canal, or enteron, where it is digested and absorbed by the endoderm cells, while the indigestible *débris* is extruded by the anus. Such an animal has now an anterior and a posterior end, and if it moved through the water, one would expect it to go with the mouth end first, so that food particles coming in its way might be swallowed.

The next stage of importance occurs by the enormous thickening of the mesoglœa so that the endoderm and ectoderm lie at a considerable distance from each other. Fig. 40, I, represents a longitudinal, and 40, II, a transverse section through such an animal. Both ectoderm and endoderm are broken up into three layers, namely, the epithelial, the nervous, and the muscular. The inner or muscular layer lies next the thick mesoglœa. In some living Cœlenterates the mesoglœa is very thick, and into it the muscle processes dip, and even cells from the ectoderm and endoderm migrate. Such a partially cellular condition of the mesoglœa gives the starting-point for the **Cœlomata.** Externally (Fig. 40, I and II) is the protective or epithelial layer of cells, then comes the nervous layer, then the muscular layer, then a wide space filled with a gelatinous excretion and containing cells which have wandered in from the ectoderm and endoderm, then comes the endodermal muscle layer, then the nervous layer, and then the epithelial layer of digestive cells, and lastly, in the centre of the animal, the cavity of the gut or enteron. In actually existing **Cœlomata**, however, there is no mesoglœa, but a space called the **Cœlome** occupying its place. And during development, from the gastrula stage onwards, into this space wandering cells migrate and give rise to a third cellular layer, the **mesoderm.** From this the blood-

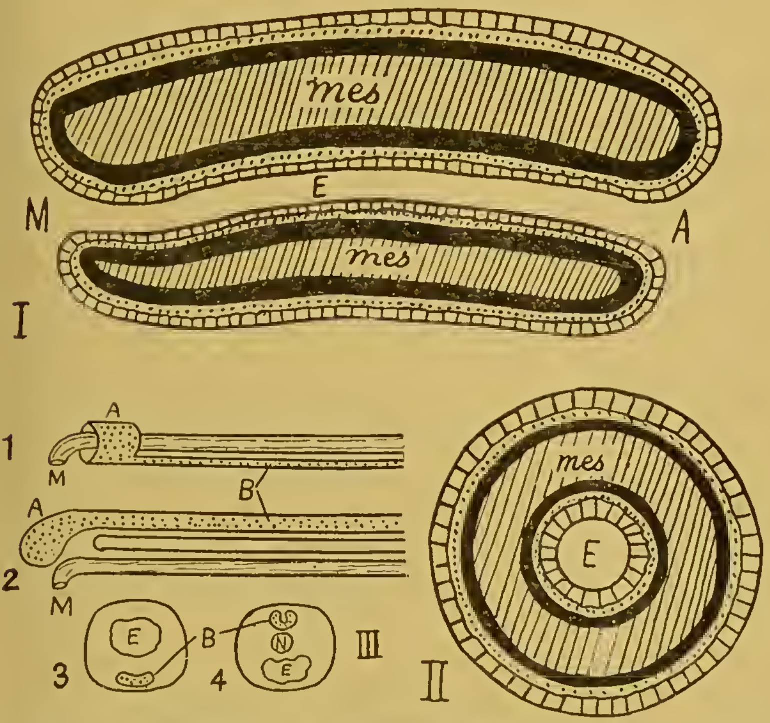

FIG. 40.—I. Longitudinal. II. Transverse section through an animal with very thick mesoglœa, mouth, anus, enteron; ectoderm and endoderm broken up into three layers, muscular next the mesoglœa, then nervous, and then protective in the ectoderm, digestive in endoderm. In Cœlomates mesoderm tissues and the cœlome occupy the space here filled by mesoglœa.

M. Mouth; **A.** anus; **E.** enteron; **Mes.** mesoglœa. Black layer is muscle, dotted layer is nervous; layer divided into cells is protective in ectoderm, digestive in endoderm.

III. Nervous system of Cœlomates—**1.** An invertebrate type; the nervous system forms a ring round the alimentary canal in front and a longitudinal ventral band below it. **2.** The vertebrate type; the nervous system forms a bulb in front, a dorsal tube behind, both above the alimentary canal and separated from it by a special rod of cells—the notochord. **3.** Cross-section through posterior part of **1.** **4.** Cross-section through posterior part of **2.**

M. Mouth; **A**, anterior; **B**, posterior parts of nervous system; **E**, enteron; **N**, notochord.

vessels, blood, and the connective tissues and skeleton are formed. The muscular layers, instead of being formed from the ectoderm and endoderm in definite layers, usually arise as solid buds of mesodermal cells coming chiefly from the endoderm, or else are differentiated from the mesoderm itself. The mesodermal buds afterwards arrange themselves around the endoderm of the gut and around the inner side of the ectoderm, so that their final position is similar to that in the diagrams of Fig. 40. These mesodermal tissues fill up a considerable part of the space originally occupied by the mesoglœa. But in all Cœlomates there is present a hollow space lying within the two mesoderm layers and lined by a special epithelium. This space is called the **cœlome,** and its epithelium is the **cœlomic epithelium.** This epithelium is a specialized layer of the mesoderm. The existence of this cœlomic cavity lying between the alimentary canal or enteron and the body-wall is the leading characteristic of **Cœlomates,** from which their name is derived. The Cœlomates, on account of the third or mesodermal layer of cells lying between the endoderm and the ectoderm, are often distinguished as the **Triploblastica,** or the three-layered animals, but it is necessary to remember that this middle layer is not a simple epithelial layer like the outer and inner layers, but is a composite structure composed of contributions from the others.

Finally we have to consider a set of changes which occur in the nervous layer. It will be remembered that there are two layers of this. The endodermal nervous layer surrounding the alimentary canal either disappears or becomes the special nervous apparatus of the wall of the gut. The ectodermal nervous layer gives rise to the chief nervous structures of the adult, and, among Cœlenterates generally, it becomes specially thickened in certain regions. Thus even in *Hydra* the nerve cells are more abundant on the tentacles. In many anemones this occurs very markedly, while in medusæ special thickenings or concentrations occur around the tentacles, around the margin of the umbrella-like swimming bell, and in other places. Instead of forming a scattered layer of ganglion cells these become aggregated and concentrated in tracts and regions where the nervous cells are specially useful. When in the course of evolution the gastrula became elongated and took to moving mouth first through the water, it is plain that it was the anterior region of the body that first received impressions in connexion with the outer world. The process of the survival of the fittest, operating upon individuals of different organizations, accordingly resulted in the anterior region around and above and below the mouth becoming the region of special developments of the nervous layer. Most often in the region above and in front of the mouth a specially large collection of nerve cells occurs, and such a collection may be called a **brain,** while the part of the body in which it lies may be distinguished as a head. In addition to this thickening of the ectodermal nervous layer in the front end of the body, thickenings in other regions occur among different cœlomate animals. Of these, two types require attention. In many animals like earthworms and leeches, crayfish and lobsters, and in insects, in addition to the nervous layer in the anterior region there is a concentration, or special development of it, all along the under surface in the middle line from the mouth to the anus (Fig. 40, III, 1 and 3). As this is the arrangement in the most commonly known animals that do not possess a backbone, it is often spoken of as the invertebrate type of nervous system. On the other hand, among those animals that do possess a backbone, such as fishes, frogs, reptiles, birds, and mammals, there is a special concentration of the nervous system along the middle line of the upper or posterior surface (Fig. 40, III, 2 and 4). This is the spinal cord, which runs from the brain down the middle line of the back, protected by the arches of the backbone.

Let us now sum up the characters of the two groups into which the Metazoa are divided. The Cœlenterata consist of Metazoa built upon the type of the gastrula. In them the body-wall consists of two cellular layers, the ectoderm and the endoderm, separated by the mesoglœa, a jelly-like supporting layer which is not composed of cells.

The two-layered wall surrounds a central digestive cavity, the enteron, which communicates with the exterior by an aperture serving both as mouth and anus. The Cœlomata contain those Metazoa in which, in addition to the ectoderm or endoderm, there is a third set of cells, the mesoderm, lying between them. The cells of this are derived from the ectoderm and the endoderm. Within the mesoderm there is a second cavity, surrounding the enteron or primitive digestive cavity, and called the cœlome. The ectodermal nervous layer becomes concentrated in at least two important regions, an anterior region around the mouth, and a longitudinal tract along the body, which is ventral in position among the invertebrata and dorsal among the vertebrata.

CHAPTER XXII

THE TRIPLOBLASTIC CŒLOMATA

THE EARTHWORM

THE earthworm is a convenient type of triploblastic cœlomate to examine, as it is large enough to dissect and soft enough to cut into microscopic sections without great difficulty. Earthworms belong to many different genera, and are found all over the world, living in the earth, in mud, or some of them in water. Most typical examples live in the ground. As Darwin showed, their food consists of organic matter, chiefly vegetable, which they obtain from the soil by passing great quantities of earth through their alimentary canals. In large measure they live upon decaying leaves or any decaying vegetable fibre. In the process of digestion the nutritious organic matter is absorbed by the alimentary canal, and the indigestible part, together with soil, is discharged by the anus in a finely triturated condition, forming the worm-castings familiar to every one. In this way worms pass a very large quantity of the soil through their bodies, and, as the castings are deposited on the surface of the ground, stones and other objects on the surface are gradually undermined, and in the course of years buried in the soil.

The different kinds of earthworms vary in size. The smallest are no thicker than a piece of packthread, and may be less than a quarter of an inch in length. Some of the largest, as, for instance, the giant earthworm of Australia, may be six to eight feet long, and at the thickest region of the body have a girth the size of a man's wrist. The common earthworms of England belong to more than one genera, and there are several species. The two genera most common in England are *Lumbricus* and *Allolobophora*. In the English species the genera may be distinguished by the dorsal surface of the first segment. In *Lumbricus* the prostomium is prolonged back to the constriction between the first and second segments ; in *Allolobophora* the prostomium does not reach so far (Fig. 41, *a*, *b*). The common large worm, about six inches long, with flattened tail and whiter lower surface, is *Allolobophora terrestris*, commonly in error called *Lumbricus terrestris*. The smaller sized common red worm with white clitellum is a *Lumbricus*. Into the separate characters of species it is unnecessary to enter, as any of them will serve our present purpose. For the most part they live underground, and specimens found crawling on the surface are generally diseased. But on a summer evening, especially after rain, earthworms may be seen in immense numbers on the surface of any lawn. Each remains in connection with its burrow by the flattened part of the tail, and the slightest touch or vibration on the ground causes it instantly to retire within the burrow. The mouth of the burrow is guarded, sometimes by a small stone, more often by a leaf pulled down stalk first. The sides of the burrow are always damp and slimy, the slime being a secretion from the glandular cells on the outer surface of the skin, and possibly also a fluid discharged from the cœlome of the animal through a series of dorsal pores.

The earthworm is an elongated animal, pointed at both ends, and flattened towards the posterior end. The colour varies from a red-brown to a pale yellow-brown, and is darker on the upper surface and generally at the anterior end. It is constricted externally into a number of rings or **somites,** of which there may be different numbers in mature specimens of the same species. These may be so few as sixty-eight, or may be more than two hundred. This is the first instance we have had of what is known as **segmentation,** and the segmentation is called **metameric** when the segments form a longitudinal row.

It is a phenomenon of frequent occurrence among Cœlomates. Sometimes, as in many worms, in lobsters and crayfish, and in insects, the segmentation is obvious on the outer side of the body. But, in addition, many of the internal organs, such as muscles, nervous structures, genital organs, and bony parts (as the backbone of a fish or of a man) also may be segmented. The segmentation of the internal organs may correspond to that of the external surface of the animal, so that the whole body is broken up into a series of rings, each ring being practically a repetition of the ring next in front. More often, as in man, the segmentations of the different internal organs do not completely agree and do not correspond with external marks. Thus our body can hardly be said to be segmented externally. At the most it is broken up into three regions—the head, the fore part of the trunk with the arms, and the hind part of the trunk with the legs. To a certain extent the muscles are segmented, but these segments do not correspond with the divisions of the outer surface. The lungs, the heart, the alimentary canal, and the kidneys are unsegmented, while the nerves, the ribs, and the backbone are highly segmented. So far as observation goes segmentation is a phenomenon that may occur in almost any cœlomate tissue, and although the result of it is to produce an appearance of similarity—just as from a balloon at a considerable height a row of elephants and a row of corn-ricks would closely resemble each other—there is no necessity to suppose that segmented animals or tissues are really more like each other than are unsegmented animals or tissues.

The whole of the body is invested with a delicate transparent iridescent cuticle. This is not composed of cells, but is formed as a secretion by the external cells of the body-wall. When a worm is placed in spirit the cuticle becomes separated from the underlying cells, and strips off easily. If the anterior, more pointed end be examined carefully with the naked eye, and with a small pocket lens, it may be seen that the most anterior segment is complete posteriorly, but that it ends anteriorly in a rounded lobe overhanging a wide aperture looking downwards and forwards. The aperture is the mouth; the projecting lobe is termed the **prostomium**, and if a living worm be examined one can see that the prostomium is used as a delicate organ of touch, and that it is more sensitive than the rest of the body. The posterior segment of the body has a vertical slit between two humid lips, on the posterior or terminal surface. This is the **anus.** Near the anterior end of the body—actually in segments 29–35—there is a whitish, swollen, saddle-shaped patch—the **clitellum.** This is most apparent on the back of the animal, and, except during the breeding season, it is not a conspicuous object. It is a patch of the ectoderm, the walls of which are glandular and secrete a **cocoon,** within which the mature ova and spermatozoa are placed.

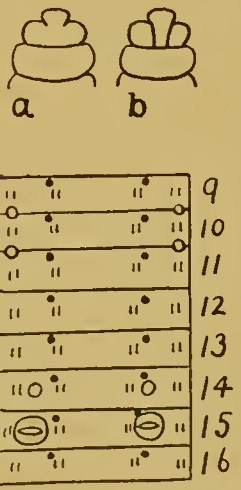

FIG. 41.—**a.** Prostomium and first and second segments of Allolobophora; **b.** same of Lumbricus. The lower figure is a diagram of the ventral aspect of segments (**9–16**) of an earthworm. The short strokes, arranged in pairs, are the setæ: the round dots in front of the outer setæ of the inner pairs are the nephridial pores. The spermathecal apertures are between **9** and **10**, and **10** and **11**; the apertures of the egg ducts are in **14**, and of the male ducts in **15**.

If a finger be passed along the ventral flatter surface of an earthworm from the posterior to the anterior region, it will be felt that that surface is not smooth like the rest of the earthworm, but is studded with sharp bristle-like points. These are curved open **S**-shaped bristles of a horny material which is common among invertebrate animals, forming, for instance, the hard outer cuticle of beetles, and called **chitin.** In the common earthworm there are eight setæ on each segment except the anterior and posterior segments (Fig. 41). These eight are arranged in four longitudinal rows (two lateral and two ventral), the spaces between the longitudinal rows being flattened. The ventral rows are on the paler ventral surface: the lateral rows lie parallel with them, where the darker colouring of the upper part of the body begins. The setæ are embedded in blind sacs of the epidermis, projecting into the cœlome, and they are formed by an excretion from the cells lining the sacs. A powerful set of muscles is attached to each sac, and by means of these muscles the setæ form the locomotor apparatus of the earthworm. When cast off, the setæ are replaced, and young setæ occasionally may be seen alongside mature examples.

In addition to the mouth and anus there are other external apertures. The **dorsal** or **peritoneal pores** are small apertures situated in the middle of the constrictions separating the segments. If the body of a newly killed earthworm be gently squeezed, a small drop of fluid exudes from each pore, and it may be seen that there is one of them in every constriction except near the front end of the body.

The orifices of the excretory organs, or **nephridia,** are very small, but in large specimens they may be seen with the aid of a hand lens. There are two orifices in each segment; each lies just outside and in front of the external seta of the inner longitudinal row.

The sexual apertures are more conspicuous (Fig. 41). In the common earthworm, on the ventral surface of the 15th segment (the segments should be counted, as variations in the position may occur) are a pair of large slit-like apertures guarded by swollen, light-coloured, tumid lips. These are the external openings of the male organs. In a line with these, on the segment next in front, are a pair of smaller apertures, the female openings.

The ventral surface of a few of the segments in front of this (9 to 11), especially in the breeding season, is swollen, and resembles the clitellum. In line with the lateral setæ at each side there is present a small opening between the 9th and 10th, and between the 10th and 11th somites. These are openings of accessory reproductive organs termed the **spermathecæ.**

All the external characters should be made out on a living or a newly killed worm.

Killing by chloroform contracts the muscles and distorts the animal. The dissection should be performed upon as large a specimen as possible, killed by immersion in methylated spirit for two minutes, and then washed under the tap for half an hour. A specimen so treated is quite limp, and should be dissected under water in a shallow dish provided with a false bottom into which pins will stick. A sheet of cork weighted with lead, or a layer of paraffin run into the bottom, serve this purpose equally well. In the course of dissection the dish should be placed under the tap at frequent intervals, so that all *débris* that makes the water cloudy may be removed. The dorsal wall must now be slit up carefully along the middle line, and the two flaps pinned back to the cork. The spacious cœlome or body cavity, containing the alimentary canal and the internal organs, is exposed by this incision, and one sees at once that it is divided by a series of **mesenteric septa**—delicate membranous partitions usually coinciding with the constrictions between the segments, except in front of the fourth segment. Occasionally septa may be more numerous than the segments. In order to pin out the flaps widely and expose the internal organs fully, it will be found necessary to cut through the septal attachments to the body-wall for a short distance on each side of the original longitudinal incision.

Before proceeding further with the dissection, the general arrangement of the organs should be examined carefully. The most conspicuous organs which are first seen are: anteriorly is the **pharynx,** a wide, muscular sac reaching from the anterior end to nearly the 8th segment; behind this it narrows and is overlaid by other structures, but in about the 15th to the 21st segments it is again visible as two rounded muscular masses—the **crop** and **gizzard,** the latter being separated by a constriction from the intestine. This is sacculated, expanding in the segments and constricted at the septa; near the posterior end of the body it gets rounder, and narrows until it reaches the anus. The outer or cœlomic surface of the intestine is covered by a greenish-yellow layer —the **chloragogen cells.** Running along the dorsal middle line of the alimentary canal from the hinder end of the body is a bright red tube—the **dorsal** or supra-intestinal **blood-vessel.** It ends anteriorly in the region of the pharynx, over which it ramifies. In each segment a pair of blood-vessels are received by it, and come in from the inner side of the body-wall. In segments 7 to 11 there are five large and conspicuous vessels—the **pseudo-hearts.** In the living worm their muscular walls are contractile, and they serve to propel the blood.

The alimentary canal and the other organs are generally covered and obscured by large, whitish, hollow, irregular masses stretching from about the 8th to the 15th segments. These are the **vesiculæ seminales**—reservoirs of the seminal fluid. In the breeding season (Fig. 43, right side) they are so large and conspicuous that, even before the earthworm is opened, they may be seen bulging the body-wall out. There are three at each side and two large median ones. When they are not well developed, there may be seen between them three pairs of expansions of the wall of the alimentary canal between the pharynx and the gizzard. The anterior pair, about the 10th segment, are the **calciferous pouches** —glistening, whitish organs; and the succeeding two pairs in the 11th and 12th segments are the **œsophageal** or **calciferous glands.** Immediately behind them, the alimentary canal expands to form a soft-walled sac called the **crop,** which passes into the muscular **gizzard.** In the 9th and 10th segments, laterally just under the edge of the

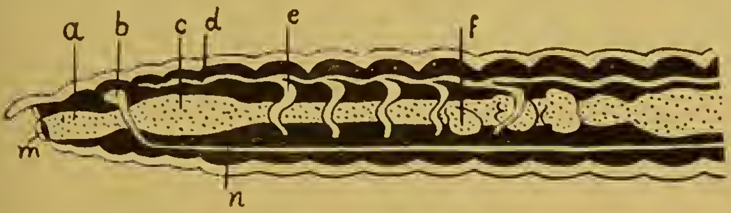

FIG. 42.—Diagrammatic longitudinal view of the fore-part of an earthworm opened from the left side. The cœlome is the black space; the alimentary canal is the dotted tube passing from the mouth backwards. The nervous system and blood-vessels are in white. **m.** Mouth; **a,** wall of buccal cavity; **b,** cerebral ganglion from which the nerve-collar runs round the alimentary canal to be continued as **n,** the ventral nerve-cord; **c,** pharynx; **d,** dorsal blood-vessel; **e,** anterior of the five hearts which lead from **d** round the œsophagus; **f,** calciferous pouch; in the succeeding two segments are the calciferous glands.

vesiculæ seminales, may be seen two pairs of rounded white bodies—the **spermathecæ**—the external openings of which have already been described.

The septa are specially strong in the anterior part of the body, and owing to the lateral stretching of the body when the flaps were pinned out, it will be found that the septa are bent so that they overlap each other. But in the region behind the gizzard, the segments are larger and the septa straighter. In this region a pair of **nephridia** may most easily be seen in each segment. Each nephridium is a small coiled structure closely attached to a mesentery, and lying under and to the side of the alimentary canal.

For more detailed dissection the different organs must be taken separately, and if it be found that the examination of one set of organs has injured another set, another worm should be dissected, special care being taken with the organs imperfectly seen in the first.

Alimentary canal (Fig. 42). This consists of a straight tube running from the mouth, which opens from the ventral side of the 1st segment, and is overhung by the prostomial lobe, to the anus, which is posterior and surrounded by the last segment. The mouth cavity or **buccal sac** leads into a very short constricted part, which is surrounded by the nerve collar, and this leads into a wide, very thick-walled muscular **pharynx**, which extends to the 6th segment, and is bound to the body-wall by fan-shaped strands of extrinsic muscles. From the posterior end of this emerges a narrow **œsophagus**, which runs back to the 15th segment. Midway on this are three pairs of protuberances—the calciferous pouches and glands. The first pair lie in segment 10, and have a narrow opening into the gut. The second and third pairs lie in segments 11 and 12, and are closed cavities except their opening into the calciferous pouches; their walls are lined by horizontal lamellæ. The glands when opened are found to contain a milky-white fluid secretion. Under the microscope this is seen to contain numerous rounded solid bodies, and, in the first pair, rhombohedra and large concretions. These are calcareous bodies, soluble in acetic acid with the evolution of carbonic acid. The function of the secretion is unknown, but probably the calcareous fluid serves to neutralize the organic acids which at the rise and fall of the year are largely developed as the result of rapid vegetable decomposition. In the 15th segment the œsophagus begins to expand, and widens until the 18th segment, where it forms a large muscular and extensible **crop.** It may act as a temporary storage organ for food. Behind the crop is the **gizzard.** This is a grinding or triturating organ, and its wall is extremely thick and muscular. Its interior is lined by a thick, chitinous secretion which protects the wall while the stones and hard particles taken in are rubbed down. The gizzard, like the crop, is to be considered as a modified part of the œsophagus. Behind it, the alimentary canal passes into the sacculated **intestine,** which passes straight back to the anus. The pharynx should now be cut across, and the whole alimentary canal from the cut portion to the anus should be removed from the body, slit open along one side, washed out, and examined. In the intestine a striking feature is the **typhlosole**—a fold of the dorsal wall hanging down half-way into the cavity of the gut. The intestine is an epithelial tube lined with endoderm and invested in two very thin muscular layers. Of these, the muscle fibres are arranged in a circular direction around the intestine in the inner coat, and longitudinally along the intestine in the outer one. The muscular layers do not dip down into the typhlosole, which is epithelial in composition, and serves to increase the secretive and digestive surface of the intestine. The typhlosole extends back along the whole length of the intestine to within a short distance in front of the anus.

Cœlome. The spacious cavity in which the alimentary canal lies, and which is broken up into successive segments by the septa, is the cœlome. It is lined throughout by a delicate flattened layer of cells, the nuclei of which can be seen in transverse sections. This layer, or epithelium, is reflected over all the organs lying in the cœlome. The cœlome communicates with the exterior by the dorsal pores and also through the nephridia and the genital ducts. The fluid within it contains amœboid corpuscles and large round cells loaded with granules.

To examine the cœlomic fluid and the blood, a small earthworm should be killed with chloroform. As soon as it is dead the cœlome should be opened by a small slit in the middle dorsal line, care being taken to avoid the dorsal blood-vessel. The slit should be large enough to introduce a very small pipette or the point of a camel's-hair brush, by which drops of the cœlomic fluid are to be transferred to a glass slide. These drops may be examined in the fresh condition under a cover-glass, but it is advantageous to kill and fix the cœlomic corpuscles by holding the glass slide with the drop on its under surface over a few drops of osmic acid in a watch-glass. The drop on the slide must not be allowed to touch the acid. The vapour rising from the watch-glass is sufficient for the purpose.

The blood is to be examined in the same way, a few drops being removed from a large blood-vessel. The blood consists of a pale-yellow serum in which float colourless corpuscles. The colour, which is red in a thicker layer or when seen in the blood-vessel, is due to **hæmoglobin,** the same pigment as that found in the blood of vertebrates. But in them the serum is colourless, and the hæmoglobin is contained in the corpuscles.

The corpuscles of the earthworm are very small. Each contains a large nucleus similar to those which are found in the cells lining the blood-vessels. These corpuscles are therefore unlike either the red or the amœboid corpuscles of vertebrates. The amœboid corpuscles found in the cœlome are most probably the representatives of the white corpuscles of vertebrates, and, like them, they have been observed in the process of ingesting, and so destroying foreign bodies like bacteria which have found their way into the body of the earthworm.

The lining epithelium of the cœlome is modified in certain special regions. The yellowish layer of **chloragogen** cells covering the intestine has already been mentioned. These are in special connexion with the plexus of blood-vessels which ramifies over the intestine; they extract waste substances from the blood, and when they are laden with them, the cells are bodily discharged into the cœlome, from which they are removed by the **nephridia.**

Next, it is on the lining epithelium of the cœlome that the sexual cells are produced; the testes and the ovaries, presently to be described, are little buds of cells jutting into the body cavity from its lining wall, and the sexual products escape from the cœlome by the sexual ducts.

Sexual organs (Fig. 43). The **ovaries** are a pair of minute rounded, conical bodies projecting into the cavity of segment 13 from the posterior wall of the segment separating segment 13 from segment 12. They are very small except in the breeding season. In order to see them one must carefully raise the upper edge of the septum to which they are attached, by a small pair of forceps, when the little conical projections are visible, one at each side of the middle line. Hold up the septum with the left hand; in this position the portion of the septum to which the ovary is attached may be cut off with fine scissors, and the whole transferred to a slide and examined in water or glycerine. Staining on the slide with a quickly acting pigment like eosin or methyl green is an advantage. At the pointed or free end, if the worm were sexually mature, lie ripe eggs. These are large round cells with a distinct wall, the **vitelline membrane,** granular cell-body, which consists of protoplasm loaded with spherical particles of **food-yolk,** and with a large round nucleus or **germinal vesicle.** Within this may be seen one or two nucleoli or **germinal spots.** Behind the ripe eggs lie younger ova in different stages of ripeness, and these pass into a mass of small cells, which are in continuity with the cœlomic epithelium. In the 12th segment occasionally there are to be found, especially in young worms, a second pair of very small ovaries similarly attached to the septum between segments 12 and 11.

The septum between segments 13 and 14 must next be raised with the forceps, and there is to be seen closely applied to its anterior face, and exactly opposite the ovaries, a pair of short, wide funnels. These are the openings of the **oviducts,**

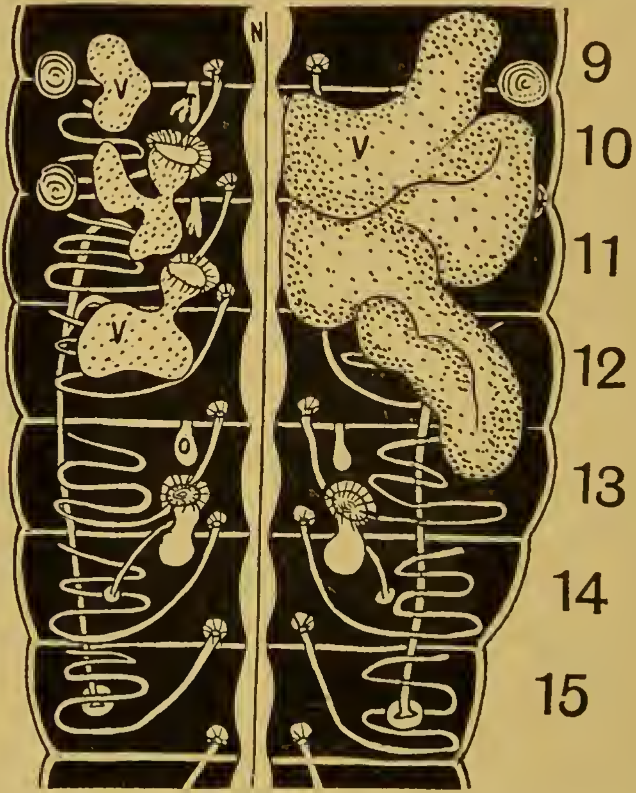

FIG. 43.—Genital segments, diagrammatic dorsal view, the intestine having been removed. The cœlome is black, the septa and nervous cord (**N**) white. The right half represents a mature, the left an immature, worm.

Spermothecæ: laterally in segment **9** bulging out septum between **9** and **10**; the second pair lie similarly in segment **10**, but the right is covered by the vesiculæ seminales. **Vesiculæ seminales (V)**, on the right, form large bulbous masses from segments **9** to **13**; on the left, they lie on septa **9–10, 10–11**, and **11–12**, the two latter communicating with the seminal funnels. **Testes (T)**, on the left, attached to the posterior wall of septa, **9–10** and **10–11**; on the right, concealed by vesiculæ seminales. **Vas deferens** runs back from the seminal funnels under the nephridial coils to segment **15**. **Ovaries (O)**, attached to septum **12–13** in line with the testes. Opposite them are the oviducal funnels in segment **13**, with the **receptacula ovorum** bulging into **14**; from the side of the funnels the oviducts run back to openings in **14**.

Nephridia. The preseptal funnels lie on the sides of the nerve cord in every segment; the coils are visible except when they are covered by other organs. (Partly after Beddard.)

and these ducts are short tubes running through the septum to the external openings on segment 14. Each, as it passes through the septum, is in close connexion with a small backward-directed pouch of the septum projecting into segment 14. The walls of these are highly vascular, and so are conspicuous, although small. They are **egg-sacs** or **receptacula ovorum,** in which eggs may sometimes be found, but in the common earthworm they are of little importance. In some of its allies, however, these egg-sacs are enormous, extending a great way down the body. The **testes,** the male organs corresponding to the ovaries of the female, consist of two pairs lying attached to the posterior face of the septa between segments 9 and 10 and between segments 10 and 11, in positions in line with the ovaries. Attached to the anterior faces of the septa, one opposite each testis, are the **seminal funnels.** These are large opaque-white membranous funnels, the walls of which are much folded and are lined on the inside by ciliated cells. They are sometimes called the **ciliated rosettes,** on account of the ciliated condition and rosette-like folding of their wall. Each funnel passes into a small tube—the **vas efferens**—which pierces the septal wall. The two vasa efferentia of each side unite in segment 12 to form at each side a single narrow tube, the **vas deferens,** which runs back to the male opening on each side of the middle line on the ventral surface of segment 15. The vas deferens is partially buried in the body-wall and therefore difficult to see.

In immature specimens of either *Allolobophora* or of *Lumbricus*—that is to say, of any of the common earthworms—the testes, funnels, and ducts are visible when the alimentary canal has been removed (Fig. 43, left side). But the case is different in adults. In *Lumbricus*, in both the 10th and 11th segments, there is a large median sac formed as an outgrowth of the septal wall called the **median sperm reservoir** or **vesicula seminalis.** These reservoirs are prolonged into paired sperm-sacs in segments 9, 11, and 12, and the whole set of sacs forms a prominent irregular white collection of pouches, which contain a thick fluid in which are floating developing masses of spermatozoa. The median reservoirs enclose the testes and the funnels, and it is necessary to slit them open and wash out the contents before the testes and funnels can be seen. In *Allolobophora*, and therefore in the common worm used for dissection, there are no median reservoirs, but there are three pairs of seminal sacs corresponding to the paired outgrowths present in *Lumbricus*. In the mature condition these are large and bloated and have contents similar to those of *Lumbricus*. Occasionally they grow into each other, but to find the testes it is necessary not to cut into them, but to displace them or to remove them entirely.

A small portion of a testis should be removed, stained with eosin, and teased with needles. It contains small irregular cells with large nuclei: these are parts of the **germinal epithelium,** which, as in the case of the ovary, is a special patch of the cœlomic epithelium. Among them are present larger cells produced from them. These larger cells are the **spermospores** or **sperm-mother cells**, each of which by division gives rise to a large number of **spermatozoa**. The spermospores are set free from the testis, and by rapid cell-division give rise to oval tuberculated masses containing many nuclei. Each mass may be called a **spermatophore** or **sperm-blastophor.** It consists of a central non-nucleated sphere of passive protoplasm, surrounded by tiny rounded cells, each with a nucleus. These are the **spermoblasts.** It is said that each spermoblast elongates, and while its protoplasm produces the tail of a **spermatozoon** its nucleus forms the head. At a later stage in development, the central sphere of passive protoplasm is surrounded not by the mulberry-like spermoblasts, but by the filamentous spermatozoa. In order to see the different stages in the development of the spermatozoa a small drop of the milky juice contained in the sperm sacs or sperm reservoirs should be stirred into a drop of normal salt solution on a slide and covered with a cover-slip. It will be seen to contain numerous spermatophores in different stages. There are (1) Mulberry-shaped multi-nucleated masses. (2) Masses in which the protoplasm is arranging itself around each nucleus and projecting outwards as a filament. (3) Stages in which the filaments are prolonged to form the tails of the spermatozoa. (4) Final stages in which each spermatophore consists of a central unchanged portion of passive protoplasm surrounded by tufts of spermatozoa. Occasionally free spermatozoa, each with an elongated head and a long hair-like tail, may be seen.

Among the contents of the sperm-reservoirs almost invariably there are present stages of a unicellular animal belonging to the genus *Monocystis*. This is one of a group of parasitic Protozoa named Gregarines, which live as parasites in the bodies of cœlomates. The fully grown cell is a large granular mass of protoplasm enclosed in an elongated oval cell-wall with pointed ends. Normal salt solution does not kill it, and its shape constantly changes as it wriggles about in the fluid. There may be also seen large round cysts produced by the conjugation of two cells. The cysts are packed full of small oval sporocysts, each of which has a hard wall enclosing a tiny elongate mass of protoplasm or sporoblast. Ruptured cysts and free sporocysts are of frequent occurrence. These Gregarines, unlike the algæ found in endoderm of *Hydra*, are *parasites;* so far as is known their presence is attended with no benefit to their host, and in many cases they produce diseases. The bodies of earthworms which may be found away from their burrows lying in a half-dead condition on the surface of the ground contain numerous Gregarines of different kinds. So, too, do those which are dug up in a normal condition from the soil.

Spermothecæ. Lying in the 9th and 10th segments are a pair of very peculiar accessory reproductive organs—the spermothecæ. These two pairs of rounded globular sacs open directly to the exterior by the spermothecal pores. They contain ripe seminal fluid received from another worm during copulation.

Nervous system. When the alimentary canal, behind the pharynx, and the sperm reservoirs have been removed, there is visible, stretching along the floor of the body cavity from one end to the other, an apparently single delicate white cord. This is the ventral nervous chain. It is, however, paired and consists of two white cords enclosed in a common sheath. It is expanded in the middle of each segment, the swellings being larger in the hinder parts of the body, and in each segment three pairs of short nerves run from them, two of which enter the body wall. Of these three nerves the most anterior in each segment is the **visceral nerve,** and supplies the viscera. The two which come off close together in the middle of the segment are one of them **motor,** supplying the muscles of the segment, and the other is **sensory,** supplying the skin of the segment. If this ventral chain be traced forwards under the pharynx it may be seen in the 4th segment to separate into two branches, each of which bends upwards and forwards, the two forming a collar around the buccal sac in front of the pharynx. The dorsal part of the collar is formed by two pear-shaped ganglia lying on the constriction in front of the pharynx and united by a transverse band of fibres called the transverse commissure. These two are the **supra-œsophageal** or **cerebral ganglia** or brain, and from them nerves run forward to end in the epidermis of the prostomium.

Examination of transverse sections of the nerve cord show that it is paired throughout its length. It consists of two solid tracts of fibres, approximated to each other in the middle line. The two tracts are enclosed in a strong elastic **sheath,** which contains embedded in it, on each side, a **lateral blood-vessel.** Lying above the two nerve cords and between them and the sheath are three peculiarly modified bodies, elastic and tubular in nature, and known as the **giant fibres**. They are doubtless supporting and protective in nature, like the sheath. In structure they resemble nerve fibres, but they are much greater in diameter and very probably they have lost their nervous functions.

The metameric or segmental swellings of the nerve cord, sometimes spoken of as ganglia, are not real ganglia at all. They are not, for instance, conformable to the cerebral ganglia, which are true ganglia. A ganglion is a localized collection, or, as it were, a concentration of nerve cells. In the earthworm, the cerebral ganglia is the only situation where such a localization occurs. For throughout the length of the nerve cords the nerve cells are found uniformly distributed and occupying chiefly a peripheral position. The chief bulk of the nerve cords consists of nerve fibrils running longitudinally.

There is a difference in the origin and distribution of the sensory and motor nerves which deserves special notice. The fibrils of the motor nerves arise as outgrowths of the nerve cells, and they pass outwards and end in the muscle fibres. But the fibrils of the sensory nerves arise, not from the nerve cells but from the ectoderm cells of the skin. These constitute sensory as well as protective cells. The sensory fibrils grow inwards from the sensory epithelium (ectoderm) and upon reaching the nerve cord divide into two branches, one ascending (anterior) and the other descending (posterior), each of which ends in arborizations around a nerve cell (compare Plate IX, Figs. 1 and 2).

The earthworm is devoid of specialized sense-organs such as eyes, ears, and olfactory organs. Yet we know it is sensitive to light, and there are reasons to believe that it is sensitive also to sound and smell. The only approach to specialized sense-organs shown by the earthworm is in the presence of globular aggregations of sensory cells in the head region and around the setæ. These are probably mainly tactile in function.

Circulatory System. This system should be examined in a fresh worm dissected under 50 per cent. spirit. Immersion for some hours previously to dissection, under 5 per cent. nitric acid in 50 per cent. spirit, renders the blood-vessels more conspicuous. The blood-vessels are recognized by their bright red colour; but they are black if previously treated with nitric acid.

The **dorsal** or **supra-intestinal** vessel (Fig. 42) may be seen through the skin in a living animal. It runs from the posterior end to the pharynx, closely applied to the alimentary canal. The flow of blood is from behind forwards, and the vessel is rhythmically contractile. The **ventral** or **supra-neural** vessel is a median blood-vessel running backwards below the alimentary canal and above the nerve cord, along the whole length of the animal. Anteriorly it communicates with the dorsal vessel through a series of capillaries.

The **sub-intestinal** vessel lies embedded in the ventral wall of the alimentary canal. It receives the capillaries of the wall of this canal, which are formed by the breaking up of vessels derived from the main dorsal vessel. The **sub-neural** vessel runs along the whole length of the animal under the nerve cord. The **lateral neural** vessels run along the whole length of the nerve cord, and are embedded in the sheath. These are the main trunks of the vascular system, and they are connected with each other by a complicated system of capillaries.

The hearts are five pairs of large contractile vessels (Fig. 42) running round the œsophagus in segments 7 to 11 from the dorsal to the ventral vessel. During life the contractions pass from above downwards. In each segment a pair of vessels run round and within the body wall from the dorsal to the sub-neural vessels. In each segment at least two vessels are given off on each side from the dorsal vessel, and immediately break up into a set of meshes ramifying all over the surface of the intestine. These are covered and obscured by the chloragogen cells. A longitudinal band of this mesh-work at each side is specially conspicuous, and these two are sometimes called the **lateral longitudinal vessels.** The nephridia receive a blood-supply from the ventral vessel: a small **afferent nephridial** blood-vessel runs from this to each nephridium, upon which it breaks up into capillaries. From these an efferent nephridial vessel runs back to the sub-neural vessel.

The general course of the circulation is as follows: From the dorsal vessel blood passes through the alimentary capillaries to the sub-intestinal vessel. From this it passes through a series of segmental vessels to the ventral vessel. At the same time some of the blood in the dorsal vessel has passed forwards and flowed through the pseudo-hearts direct to the ventral vessel. From this the blood passes through the afferent nephridial vessels in each segment to the nephridia. Here it is deprived of nitrogenous waste and passes purified through the efferent nephridial vessels to the sub-neural vessel. From this it is carried to the skin and body wall by the parietal vessels, where it gives up some of its CO_2 and takes up O_2. Thence it is carried, as the purest blood in the body, through the efferent or dorsal portions of the parietal vessels to the main dorsal vessel. The circulation is thus completed. To facilitate the respiratory process the ectoderm of the earthworm shows a unique and exceptional condition. Its cells are pierced by blood capillaries. In other animals the blood capillaries lie beneath the ectoderm and do not penetrate it.

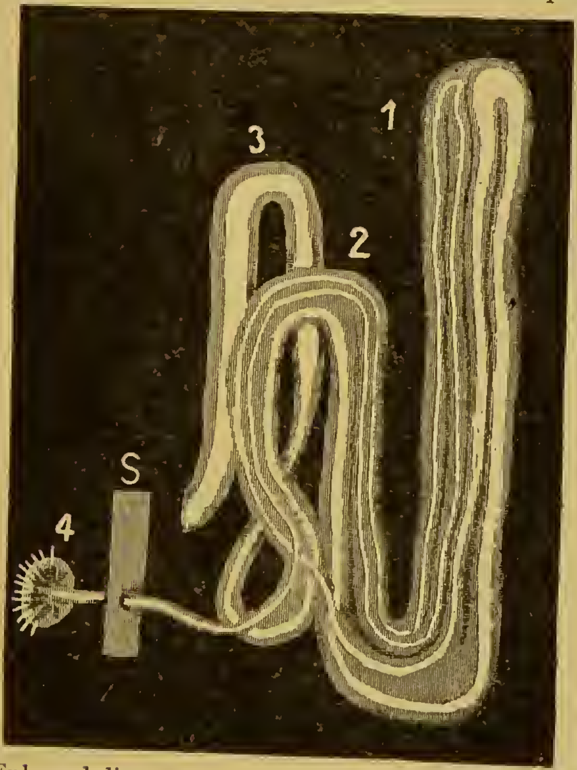

FIG. 44.—Enlarged diagrammatic view of a nephridium. **4.** The preseptal part and the funnel; this passes through the septum **S** into **2**, the middle loop. **1** is the inner loop; **3** the outer loop. (Partly after Benham.)

Nephridia (Fig. 44). To examine these excretory organs in detail it is important that the septa should not have been torn or stretched. When the alimentary canal has been removed, the worm must be washed under the tap. Each nephridium is then seen with the aid of a hand-lens as a delicate tube of three loops, whitish in colour (Fig. 44), and extending in the segmental cavity from the mid-ventral line almost to the mid-dorsal line, and is suspended to the septum by a mesentery of its own. It is divisible into a pre-septal region lying in front of the segment which bears the external aperture and a much larger post-septal region. The pre-septal region is very short (Fig. 44, 4), and consists of a ciliated funnel or **nephrostome** opening into the cœlomic cavity and a short tube passing through the septum to form the post-septal part. This part should be cut out and examined in a drop of normal salt solution under a high power. The funnel consists of a number of tall columnar cells lined by strong cilia, the motions of which sweep a current from the cœlome into the tube. The funnel opens into a narrow tube formed of a single row of cells. The cavity of this tube is hollowed out of the interior of the rod of cells through which it passes. The lumen is thus **intra-cellular.** The post-septal portion consists of three loops, and the intracellular tube or lumen passes suddenly into the ascending limb of the middle of these, and then runs down the descending limb and up and then down the inner loop, and back again to the middle loop, which it first ascends and then descends. This part of the nephridium is the largest ; it is ciliated and flagellated in places, and the ascending and descending parts are twisted about each other. (In the diagram they are drawn straight, on account of simplification.) The narrow part, after leaving the middle loop, crosses to the inner loop and runs up and down that : this part of the tube is glandular and excretory, and the cavity is much wider. Next it runs up and down the middle loop again, and finally forms the very wide tube of the outer loop which ends in the external aperture. This latter portion has an **extra-cellular** lumen, and is therefore lined by an epithelium. Muscle-fibres are also present in its wall, and by their contractions excretory matter is expelled outwards to the exterior. Through the nephrostome waste matter and effete cells contained in the cœlomic fluid are wafted through the lumen of the nephridia to the exterior. In the glandular part of the nephridia nitrogenous waste is doubtless excreted from the blood and driven by the flagellæ towards the exterior.

A dense network of blood capillaries surrounds and ramifies through the walls of the middle and inner tubes.

Minuter details of the anatomy of the earthworm must be studied by means of sections. As the amount of earthy matter in the intestine blunts the razor and tears the sections, it is advisable to keep the worms for a few days in damp moss or ground coffee, or damp blotting-paper ; or if they are placed in salt and water for a few minutes before killing they will frequently discharge the contents of the intestine. A small specimen should be chosen, and killed by immersion in methylated spirit for about two minutes. Then it should be removed to a cold saturated solution of corrosive sublimate in water to which 1 per cent. of glacial acetic acid has been added.

After immersion for half an hour in the solution, the tissues are sufficiently hardened for cutting out the pieces specially required. With a sharp razor a piece less than half an inch long, so as to include three or four complete segments, should be removed from the third quarter of the body. From this transverse sections are to be cut. Another piece should be removed from the anterior end so as to include segments 7 to 16 inclusive (of this longitudinal horizontal sections should be cut). These two pieces must be replaced in the solution for twenty-four hours, and then soaked for some hours in 70 per cent. alcohol in which a morsel of camphor has been dissolved. The spirit should be changed at intervals, until finally it remains quite clear when the pieces have been soaking in it. The pieces are then to be stained in a solution of borax carmine for at least two hours, and preferably for a fortnight, and thereafter soaked in 70 per cent. alcohol rendered acid by a drop of acetic acid until they are *bright* red throughout ; then they must be soaked successively in 90 per cent. and in absolute alcohol for at least three hours. The purpose of these soakings is to replace the water in the tissues by a liquid into which a solvent of paraffin will diffuse. The pieces should now be removed to a narrow test-tube containing about an inch of absolute alcohol. Into this an inch of chloroform, benzol, or turpentine should be poured. As the alcohol is lighter than the chloroform it will stand in a column above, and the pieces of worm soaked in the alcohol will also be light enough to float in the upper alcoholic layer. But as the chloroform gradually diffuses into the alcohol it will also diffuse into the tissues of the worm. When this process is complete the pieces of earthworm will, by their own weight, sink to the bottom of the tube. They should then be removed to pure chloroform, benzol, or turpentine, and some small fragments of solid paraffin should be dropped in with them. Gentle heat is useful to assist the solution and penetration of the paraffin. For this purpose, the best possible means is to keep the mixture of worm, paraffin, and chloroform in a corked tube in one's waistcoat pocket for a few days, or in an incubator. Lastly, the pieces of worm should be picked out and dropped into melted paraffin kept at a temperature under 60° C., in a hot chamber. If the process recommended here is followed, after an hour in the paraffin the pieces will be completely permeated.

The pieces must now be placed in little paper moulds filled with melted paraffin. Great care must be taken to arrange each piece so that it may be cut exactly in the plane required. When this has been done, as soon as the paraffin is cool enough to be opaque, the mould should be cooled by placing in cold water. Sudden cooling renders it more easy to cut. The blocks when cool must be trimmed to a suitable size, and sections cut with the microtome and placed on a slide in order. The slide should be smeared with a very small quantity of glycerine and albumen (white of egg), and then placed in a warm chamber until the paraffin has melted. Washing with warm turpentine will dissolve out the paraffin, after which the sections should be mounted in Canada balsam dissolved in chloroform.

The sections must be examined first under a low power in order that the general arrangement of the tissues and organs may be seen. Then the details of structure are to be investigated with a higher power.

Transverse section through the region of the intestine.

The general shape is round. The dorsal surface is indicated by the typhlosole, the ventral by the nerve cord.

a. **The integument.** The cuticle is thin and structureless: it is usually partly or wholly separated from the underlying epidermis by action of the re-agents.

The epidermis comes next. It is a single layer of columnar cells, with nuclei at their bases. These are either glandular "goblet cells," or more slender packing cells. The glandular cells secrete the mucus which renders the body of a living worm slimy and aids its movements in its burrow. The secretion also takes part in forming the wall of the burrow and cementing the particles of soil together, and it is doubtless to some extent a bactericide, inhibiting the growth of or destroying certain bacteria and moulds. The packing cells form by secretion the delicate cuticle. A second row of very small cells may be distinguished under this outer layer in specially good preparations. In the region of the clitellum the epidermis cells are separated by small interspaces into which capillaries run, and the whole layer is much thicker.

b. The **setæ** may be seen lodged in **setæ sacs,** which are invaginations of the skin extending deep into the body through both of the muscular layers. Young setæ may be seen lodged within the sacs, and the muscular fibres attached to work the setæ are obvious. As the sections are rarely cut exactly in a vertical plane, either two of the four rows of setæ are not always cut through in a single section.

c. The **muscular layers** of the body wall. These consist of an outer layer, the fibres of which run circularly around the body, and an inner layer which is thicker, of fibres running longitudinally. The latter, therefore, are cut across in the transverse section. The fibres are elongate columnar bodies marked by delicate longitudinal striæ and embedded in a granular matrix containing nuclei. Between the fibres and between the layers of muscle there is present a quantity of connective tissue, many of the cells of which are pigmented. This connective tissue divides the longitudinal layer into a series of radial longitudinal sheets which in transverse section have a feather-like appearance.

The **cœlome** or body cavity is the wide space between the body-wall and the intestine. It is lined by the cœlomic epithelium, a single layer of cells so delicate that only the nuclei are visible.

d. The **intestine** is the large structure occupying the middle of the section. Its diameter is about half that of the whole body. The **typhlosole** is a prominent fold of the dorsal wall extending down into the intestine and making the actual cavity crescentic. Within this cavity, however well one may have attempted to empty the alimentary tract, there is certain to be present debris of some kind. The cavity is lined by a single layer of long narrow ciliated cells. Outside this is a thicker layer of muscle fibres and connective tissue. The next outermost coat consists of a ramifying plexus of blood-vessels embedded in chloragogen cells. The blood-vessels are recognized by the blood within them, which stains deeply. The larger passages of this layer of blood-vessels known as the longitudinal vessels are usually visible. The dorsal blood-vessel lies immediately over the typhlosole, sometimes embedded in chloragogen cells, and the ventral vessel immediately under the intestine ; but these two are separate from the plexus, and vessels passing from them into the plexus may have been cut across.

Nephridia. As these are coiled tubes, in cross-section they appear as a number of circular and oblong pieces according to the way in which the plane of the section has cut across the loops. If a successive series of sections has been mounted, these pieces of the nephridia should be traced from section to section until both the funnel and the external orifice have been seen.

The **nerve cords** lie just within the longitudinal muscular layer, enclosed in a strong double connective tissue sheath, in which lie three blood-vessels—the sub-neural on the under side, and the lateral neurals at each side. Within the connective tissue sheath is a thin muscular layer which surrounds the true nerve cords. If the section passes through the middle of a segment, the nerve cords are seen more distinctly to be divided into the two cords. The body of the cords is occupied by delicate nerve fibres which give a granular appearance to the transverse section, and by large nucleated ganglion cells. These are more abundant in the ventral and lateral regions of the cord. Along the dorsal region run three large fibres with thick walls and gelatinous centres, the **giant fibres.** The function of these is unknown, but as they have been traced into nerve cells they may be part of the nervous apparatus. By some they are supposed to be supporting or skeletal structures. Lateral branches may be seen issuing from the cord running outwards and downwards into the body-wall.

The **septa** are transversely arranged in the body of the worm, and in many of the transverse sections part of one or more may be cut across. Such appear as very thin sheets of connective tissue with a few muscular fibres running in them.

Longitudinal Horizontal Section through the Genital Organs.—These will differ very much according to the plane from which they are taken, and it is very instructive to study the whole series from the dorsal surface to the ventral surface. This should be done under the low power, as otherwise it is impossible to understand the relative positions of the organs. The most useful are those passing through the levels of the funnels of the genital ducts, although of course it will be extremely improbable that a single section will pass through many of these. As the septa running across the section are very visible, it is not difficult, after a little study and comparison with drawings of the dissected worm, to identify the sections and the organs.

The integument and epidermis running along each side of the oblong section exhibit nothing not seen in transverse sections.

The fibres of the external, or circular, muscular layer will be seen cut across, while the fibres of the inner, or longitudinal layer, run along the section on each side.

The cœlome will appear as a longitudinal space between the muscles within the muscular layer, and broken up into compartments by the septa. The plane of the section will probably lie below the intestine except in the region of the gizzard, a small portion of the lower part of which will be visible. Notice the thick muscular wall and the chitinous layer lying within the endodermal epithelium and formed from it as a secretion.

The nephridia will appear much as in the transverse sections.

The septa will exhibit the same structure as in transverse section, and it will be noticed that they are pierced by the blood-vessels, alimentary canal, and genital ducts.

The genital organs occupy positions indicated in Fig. 43, but their relation to each other and to the septa are more apparent.

After the anatomy of the earthworm has been studied, it is well to consider the parts played by its complicated system of organs in the life of the animal. We saw how *Hydra* differed from a mere colony in that its cells performed their specialized functions for the general benefit of the whole organism. In the more complicated structure of the earthworm this subordination of the parts to the whole is more marked. Nutrition is now served by an elaborate alimentary canal, the various parts of which have distinct functions. The food, which consists of organic matter in the soil, is swallowed by means of the buccal cavity and pharynx ; it is ground up in the gizzard, and no doubt digestive juices are poured on it from the cells of the intestine. These certainly ingest from the mass in the gut the nutritious particles, which are in turn handed on to the blood as more elaborated products, and from the blood all the cells of the tissues and organs pick up what nutriment they require. The cells discharge their waste liquids into the blood, and from it the nitrogenous waste is removed in two ways. The chloragogen cells, which cover the capillaries of the intestine, extract waste matter from the blood and liberate it into the body cavity, whence it escapes by the funnels of the nephridia. Next, the blood capillaries on the middle and inner loops of the post-septal parts of the nephridia afford opportunity for the glandular cells of these tubules to pick out more waste matter, which, along with matter coming in by the funnel, is discharged by the nephridial apertures.

There is in the common earthworm no special organ of respiration. But along with the earthy matter taken into the intestine much air is doubtless swallowed, and from this the abundant blood-vessels of the gut may absorb oxygen and no doubt return to it carbonic acid, the cells of the gut performing or aiding the transfer. But the chief respiratory surface is the skin, the ectoderm cells of which are pierced by blood capillaries (*supra*, p. 177). The oxygen combines with the hæmoglobin dissolved in the blood, and is carried to the different tissues and cells of the body, from which again carbonic acid is returned to the gut and skin to be discharged. Associated with the functions of the blood as a carrier of food and of waste matter, of oxygen and carbonic acid, is the fact that it circulates in a closed system of vessels, the contractile hearts and dorsal vessel providing the propelling force.

The reproduction of the earthworm also is complicated. Some of its near allies can reproduce by budding, but although the earthworm has a limited power of reproducing parts accidentally lost, it has not the power of vegetative reproduction. Its normal method is sexual. As it has both male and female organs in the same individual it is a **hermaphrodite.** Cross-fertilization is secured by a peculiarly complicated process in which two individuals are involved. First two worms A and B copulate, and spermatozoa are passed from the male apertures of A into the spermothecæ of B. In B the spermatozoa of A complete their maturation. When the eggs of B in its egg-sacs are ripe, the clitellum secretes a chitinous and elastic cocoon which invests the body ring-wise. The worm B then begins to wriggle backwards through the cocoon. As its 14th segment passes into the cocoon, it discharges its ripe eggs, and upon the cocoon coming to lie in the region of the spermothecæ, the ripe spermatozoa derived from earthworm A are discharged into it. Fertilization then takes place. Finally the worm leaves the cocoon which, being elastic, closes up at either end. Although something like 20 to 24 eggs are laid in the cocoon and fertilized and begin to develop, only one worm ultimately comes forth. The struggle for the survival of the fittest begins before independent life is entered upon. Indeed, it would be truer to say that it never begins, for at no part in the life cycle of an organism does it cease to operate, either in worm or man.

CHAPTER XXIII

VERTEBRATES AND INVERTEBRATES

THE earthworm is only one among a very large number of invertebrate triploblastic Cœlomata. Some of these, like star-fishes, water-fleas, crabs and lobsters, insects, spiders and scorpions, centipedes, snails and cuttle-fish, are very unlike it. A little reflection on the animals that we all know will convince even those who take no special interest in natural history that the common invertebrates fall into natural groups, each group containing a number of animals all more or less alike. Naturalists, from their greater knowledge of animals, would make more groups and would detect resemblances and differences unapparent to the inexpert. But the least expert would not confuse earthworms with star-fish, or either with insects or snails. These are unlike in almost every feature, and it is in little else than the characters common to all cœlomates that they resemble each other. On the other hand, if we take the cœlomate vertebrates—fishes and amphibians, reptiles, birds and mammals—although there are striking differences between the great groups, yet it is plain that they resemble each other much more closely than do the invertebrate groups. Each have the body divided into **head** and **trunk,** and the latter is continued into a **tail,** short or long. On the ventral surface of the head is the **mouth**; the head contains the **brain,** and carries **nose, eyes,** and **ears.** The trunk has never more than **two pairs of appendages,** corresponding to our arms and legs. The body has an internal bony or cartilaginous **endo-skeleton,** consisting of a **skull** or brain-box; a **vertebral column,** the upper part of which is traversed by the **spinal cord,** the great nervous continuation of the brain into the body; a **pectoral**

girdle, to which the front pair of limbs are attached ; and a **pelvic girdle,** bearing the hind limbs. In all the vertebrates the cavity of the mouth communicates by a straight **œsophagus** with a **stomach,** from which an **intestine** passes to the **anus** at the root of the tail. There opens into the intestine close behind the stomach the duct of a large organ, the **liver,** found in them all ; the front part of the alimentary canal, immediately behind the mouth, is specially connected with the function of respiration. In fishes four or five slits on each side of the neck, the **gill-slits,** establish a communication between the inside of the alimentary canal and the exterior, and blood-vessels round about these openings pick up the supply of oxygen for the whole body from the water passing through the slits. The tadpoles of frogs and the unborn young of reptiles and birds and mammals, all possess these slits in the side of the neck opening into the alimentary canal behind the mouth. The blood system of all vertebrates consists of **arteries** and **veins** connected by capillaries, and the blood is always made to circulate by the contractions of a muscular **heart** lying below or ventrally to the alimentary canal in the front part of the body, while the blood itself in them all consists of a colourless fluid, in which are multitudes of white, amœboid corpuscles, and red corpuscles coloured by a pigment, hæmoglobin, which serves to carry the oxygen. All vertebrates have **kidneys** to remove their nitrogenous waste, and the apertures by which the urine is discharged are generally closely connected with the reproductive apertures, and lie near the anus.

Minuter investigation of the anatomy and of the structure of the cells in the tissues and organs similarly shows the very close resemblance existing among vertebrates. We are led to the conclusion that, while there are many great types or classes of cœlomate invertebrates, of which the earthworm and its allies represent one, there is only one type of vertebrate cœlomate. Vertebrates are larger, and being more familiar with them, we know the differences between them more intimately ; but when we compare them with the less familiar differences among the less familiar invertebrates, we find that the vertebrates must be placed in one class, the invertebrates in many classes.

Taking a class such as the vertebrates, with which we are all more or less familiar, it is obvious that there are groups in it which we think of as higher or lower with respect to each other. Thus birds and mammals are higher than reptiles, reptiles than amphibia, amphibia than fish. Below fish, there are a number of small, less familiar animals, such as *Amphioxus* or the lancelet, *Ascidians* or sea-squirts, and *Balanoglossus*, which continue the vertebrate chain down to animals which, taken by themselves, would pass as very simple invertebrates. A similar condition of things exists among the great invertebrate groups. Common animals like the star-fish and the earthworm, lobsters and crabs, flying insects, snails, and so forth, stand near the top of a long series of animals, the lower end of each series consisting usually of inconspicuous simple cœlomate forms. Now to understand properly the resemblances and relationships among these great groups, it is necessary not simply to compare with each other the higher forms, like star-fishes, earthworms, crabs, insects, snails, and vertebrates, but first to trace downwards each separate group to its simplest forms, and then to compare with each other these simplest forms. Such a task forms a great part of the science of comparative anatomy, and within the limits of an elementary course of study it is possible to do little more than to form an idea of the method by which correct ideas may be gained. Between representatives of two groups of cœlomates like the earthworm and the dog-fish, we must look for little in common besides the simple characters common to all cœlomates.

In Chapter XXI we have dealt with the common characters of cœlomates ; it is now necessary to add a further statement, the evidence for which unfortunately is too long to be given. A particular method of progressive advance of structure is common to all the great groups of cœlomates. The simplest animals in all are least segmented ; in many cases they are quite unsegmented, and we may take it that the first or primitive stage of cœlomates is unsegmented.

The next stage of advance is shown by a great increase of segmentation, which may affect the whole body or only parts of it, or which may affect different parts or organs in different degrees. The segmentation of the skin may not be exactly the same as that of the cœlome, and the segmentations of these may be different from the segmentations of the nephridia, blood-vessels, genital organs, and so forth. The third stage is a condensation of the segmentation in different regions. The most familiar instance of this is what is called **cephalization.** Two or more of the anterior segments may be telescoped together at the anterior end to form a complicated and condensed part of the body called the head. Another familiar instance of this process we shall find to be the condensation of a number of nephridia, to form a **kidney.** Like its predecessor, the process of segmentation, that of condensation may affect separate series of structures in different regions and in different ways, and the result is to produce a number of general and misleading resemblances between higher members of different groups.

In the light of these general considerations we may sum up the relations between the earthworm and vertebrates.

The earthworm is one member standing near the head of one of the many groups of invertebrate cœlomates. It has reached the second stage of cœlomate development in that it is very highly segmented, and there is little or no trace of the third stage, the stage of the condensation of segments. The locomotor organs are not limbs, but unjointed, chitinoid setæ implanted in the body wall. The nervous system consists of a pair of cerebral or prostomial ganglia, and a paired, solid, ganglionated ventral cord. The excretory organs consist of nephridia opening into the body cavity by a ciliated funnel and to the exterior by an external pore ; these nephridia are highly segmented, there being a pair for nearly every somite in the body. The genital organs show much less trace of segmentation.

Vertebrates from fish up to man are the higher representatives of a single group of cœlomates, of which the lower members are inconspicuous cœlomates that reveal their vertebrate affinities only after minute investigation. Vertebrates are highly segmented animals, in which condensation of segments has become an important factor, resulting notably in the formation of a complicated head, and of kidneys formed by the aggregation of many nephridia. There is a well-developed internal skeleton, consisting of a skull with movable jaws, a jointed backbone through the arches of which runs the spinal cord, two pairs of limbs attached to pectoral and pelvic girdles. The central nervous system is hollow and unpaired, and lies along the dorsal side of the body, and is expanded in front into a brain lying within the head and connected with three great organs of sense—the nose, the eyes, and the ears. The vascular mechanism consists of a closed system of veins, arteries, and capillaries, through which the blood is propelled by a ventrally placed contractile heart. The blood, in addition to amœboid corpuscles, contains numerous red corpuscles with definite outlines and containing hæmoglobin. Associated with respiration there exists always, either in the adult or in the embryo, a series of paired slits leading from the side of the neck into the alimentary canal behind the mouth. The cœlome is very spacious, and the genital glands arise as paired but unsegmented patches on the dorsal internal wall of the cœlome.

The type common to the lowest members of the groups of which the earthworm on the one hand and the vertebrates on the other form the highest examples, is a simple unsegmented cœlomate animal, bilaterally symmetrical, with a dorsal and ventral surface and anterior end at which lies the mouth, a posterior end where is the anus. The lower layer of the skin consists of a continuous sheath of nerve cells and fibres, showing a tendency to become concentrated at the anterior end as a brain and in longitudinal bands along the body. These are ventral in the earthworm, dorsal and tubular in the vertebrate group. The cœlome is spacious and contains modified patches, which give rise to the sexual cells. The excretory organs consist of nephridia arranged in one or more pairs, and open into the cœlome by ciliated funnels.

The differences and resemblances which characterize Vertebrates and Invertebrates may be summarized as follows :—

RESEMBLANCES

Invertebrates	Vertebrates
All above the lower forms are triploblastic and cœlomate.	All are triploblastic and cœlomate.
With the exception of a few parasitic forms, *i.e.* tapeworm, all are traversed longitudinally by a central tube, the alimentary canal, lined by endoderm throughout most of its length, and opening at one end by a mouth, and in all except the lower forms opening at the other by an anus.	All are traversed longitudinally by a central tube, the alimentary canal, lined by endoderm throughout most of its length, and opening at one end by a mouth, and at the other by an anus.
In all cœlomate forms the gonads are apparently developed from the cœlomic epithelium.	The gonads are apparently developed from the cœlomic epithelium.

DIFFERENCES

Invertebrates	Vertebrates
The skeleton when present is an exoskeleton secreted from ectoderm.	The skeleton is mainly an endoskeleton formed from mesoderm. The notochord is of endodermic origin. The enamel of scales and teeth represents an exoskeleton homologous to that of invertebrata. The exoskeleton of tortoises and of the armadillo is mesodermic in origin.
The nervous system is paired, solid, and usually ventral in position to the gut.	The nervous system is unpaired, tubular and dorsal in position to the gut.
The morphological heart is dorsal in position to the gut.	The morphological heart is ventral in position to the gut.
If the blood is coloured, the colour is due to the coloured plasma. The corpuscles are colourless.	The plasma is pale straw-coloured or colourless. The majority of the corpuscles are coloured, a small percentage being colourless.
The ectoderm is single-layered or two-layered and does not form a stratified epithelium.	The ectoderm (except in *Amphioxus*) is a stratified epithelium.
In a large number of groups, at one period or another of development, the ectoderm is ciliated.	Except in the larva of *Amphioxus*, the ectoderm is never ciliated.
Except in a few specialised forms (*Balanoglossus*, *Cephalodiscus*) gill-slits are never present.	Gill-slits which may function throughout life (*Amphioxus*, fishes, and a few Amphibia) or are present

	only in embryonic or larval stages (most Amphibia, all Reptiles, Birds, and Mammals) are always developed.
A vertebral column is never present.	In all, except *Amphioxus* and the Lampreys, in which it is represented only in a rudimentary form, a segmented vertebral column or backbone is developed and forms the axis of the endoskeleton.

CHAPTER XXIV

THE DOG-FISH

THE dog-fish, with sharks and skates, belongs to a group of powerful, predacious, active fishes, known as **Elasmobranchs.** One of their leading characters is that the skeleton is composed of cartilage, strengthened in parts by a gritty deposit of lime, but not turned into true bone. Typically they are inhabitants of salt water, but many of them, in pursuit of prey, enter brackish estuaries or rivers for some distance. The dog-fish found around our coasts belong to several species and genera. *Scyllium canicula*, the larger spotted dog-fish, and *Scyllium catullus*, the lesser spotted dog-fish, are distinguished by the absence of a nictitating membrane, by the small size of their teeth, of which several rows are in use at the same time, each tooth having a long middle cusp and several small lateral cusps. *Acanthias vulgaris*, the spiny dog-fish, is at once recognizable by the strong spine or thorn on each dorsal fin. The teeth are small, and their points are curiously turned aside, so that the inner margin forms the cutting edge. *Mustelus vulgaris*, the common smooth-hound, has a nictitating membrane; the teeth are small, very numerous, and closely packed together, forming a sort of pavement, which is used for crushing rather than for biting.

They are great enemies of fishermen, not only destroying quantities of young fish, but lacerating and damaging edible fish which have been caught in the lines or entangled in the meshes of the nets. They are themselves nearly useless as food, their flesh, like that of many carnivorous animals, being excessively tough and of strong, disagreeable flavour. The sexes are separate, and, as will be described, the males and females can be distinguished by external characters. The eggs are large, and are impregnated within the body of the female. In *Scyllium* they are laid shortly after impregnation, enclosed in a horny capsule the angles of which are produced into long spirally twisted processes which serve to anchor them to seaweed or stones. In some other dog-fish, as in *Mustelus*, the eggs are retained within the body of the mother until the adult shape has been reached, and the young embryo is nourished from the blood of the mother by means of a tuft of blood-vessels not dissimilar to the placenta of mammals. The eggs of these dog-fishes contain little food-yolk; the eggs of others contain so much that the young dog-fish, even when it has escaped from the capsule and swims about upon its own account, carries the remains of the yolk in a small sac attached by a short stalk to the ventral wall of the abdomen.

The following description applies specially to *Scyllium canicula*, the most common dog-fish, but except in external characters it will serve equally well for the spiny dog-fish or for the smooth-hound.

Dog-fish about two feet long are most convenient for dissection. This should be done upon a wooden board with a small raised rim. The characters of the skeleton should be examined on a specimen prepared by immersing a fresh fish in nearly boiling water for a few minutes, and then scraping or brushing the soft parts away. This skeleton must be kept in spirit, as, if allowed to dry, it becomes hopelessly distorted.

External Characters.—The body is elongated, and bilaterally symmetrical. It is broadest about the level of the **pectoral fins,** where it is flattened dorso-ventrally, and ends in front in a rounded blunt snout. The hinder part is compressed laterally, and tapers to the end of the long slender tail, the last two or three inches of which are bent up at an angle. The general colour is a pale grey, spotted on the sides and back with black and brown, and lighter on the ventral surface. Along each side runs a barely perceptible shallow groove, the **lateral line,** and on the head are a number of minute openings arranged symmetrically. These lead into branching tubes, from which mucus can be pressed out, and which, like the lateral line, contain sensory organs. They are supplied by branches of the fifth and seventh nerves.

There are two sets of **fins,** each consisting of flattened outgrowths supported by an external cartilaginous skeleton. The **median** or **unpaired fins** consist of—(1) **Dorsal fins,** a large anterior fin about the middle of the length of the body, and a small posterior fin some distance behind. (2) A **ventral fin,** opposite the interval between the dorsals. (3) A **caudal fin,** forming a fringe round the tail, cut off sharply at the tip, and on the ventral side divided into a small posterior and a large anterior lobe. These caudal fins give the tail of elasmobranch fishes a characteristic shape known as **heterocercal,** and notably different from the tail of bony fishes like the herring or salmon, in which the tail fin is symmetrical above and below the middle line.

The **paired fins** correspond to the fore and hind limbs of higher animals. Those of the **pectoral pair** project out from the ventral side of the body behind the head. The **pelvic fins** are much smaller, and are placed on the ventral side of the body some distance behind the front pair. Their inner borders are close together, and are partially fused in males. In the males, also, close to the pelvic fins, and developed from their inner borders, are a pair of stout rod-like processes, pointed at the ends and projecting backwards. These are copulating organs, called "**claspers,**" and along their inner dorsal edge a deep groove runs into a blind sac under the skin of the ventral surface.

The tail fin is the chief organ of locomotion in fishes. The median fins serve chiefly to preserve the balance of the fish ; the paired fins assist in balancing, and are used also to turn and guide the motions of the fish.

External Apertures.—The **mouth** is a large, curved slit extending across the ventral side of the body a short distance from the anterior end. The **cloacal aperture** is also median, and lies on the ventral side between the pelvic fins. It is the external opening of a small chamber, the **cloaca,** into which open the intestine, the ducts of the kidneys and of the genital organs.

The **nostrils** are a pair of large circular apertures on the ventral side of the head in front of the mouth, and connected with that by wide grooves covered by flaps of skin.

The **spiracles** are a smaller pair of apertures on the dorsal side of the head just behind the eyes; they open into the cavity of the mouth. They are vestiges of gill-clefts.

The **gill-slits** are a set of five vertical slits on each side of the neck, beginning immediately below and behind the spiracle, which itself is in reality an interior gill-slit much reduced in size. Each gill-slit communicates with the pharynx immediately behind the mouth-cavity, and during life water taken in through the spiracles is passed out through the gill-slits.

The **abdominal pores** are a pair of minute apertures, lying one on each side of the cloaca. They open directly into the cœlome.

The Scales and Teeth.—The whole external surface of the body is covered by small, sharp-pointed scales, which may be felt by passing the finger from behind forwards along the surface. Where the skin bends over to form the lining cavity of the mouth the scales covering the jaws are much enlarged to form teeth. The spines of the spiny dog-fish are enlarged scales. A small piece of the skin of the common dog-fish should be boiled in caustic potash solution to dissolve away the fleshy matter and isolate the scales. These, examined under the microscope in glycerine, may be seen to consist of a four-lobed bony base which was embedded in the skin, and a backwardly-directed bony spine, tipped with enamel.

The Skeleton.—As the skeletons of all vertebrates are built upon the same ground-plan, and as the skeleton of the dog-fish exhibits a comparatively simple condition of this, it is of great importance to grasp the general features. Even in a soft-bodied animal like the earthworm there is present a considerable amount of connective tissue, forming partitions and supporting membranes between the muscle layers and muscle bundles. Such a tissue is really in function **skeletal,** or supporting; and very early in the development of all vertebrates a considerable amount of skeletal tissue appears in the shape of connective tissue cells, which migrate in between the organs and layers and form a general supporting framework. But in the case of the vertebrates the name skeleton is specially associated with supporting structures developed in connexion with the special features of vertebrate structure. These are, first, the **skull,** which supports and surrounds the brain; second, the **vertebral column,** or backbone, which lies immediately under the spinal cord or dorsal nervous tube; third, the **visceral arches,** which support the gill-slits; fourth, **the skeleton of the front and hind pairs of limbs.** But in addition to this specialization of skeletal tissue in these different places, changes in the nature of the skeletal tissue occur. The connective tissue may be differentiated into **cartilage,** and the cartilage may be strengthened by the deposition of calcareous particles. The skeleton of the dog-fish does not get beyond this condition, but in higher animals the cartilage may be replaced by **true bone.** True bone may also be formed directly, in connective-tissue membranes, as happens in the case of the bony plates which form the bases of the scales and teeth of the dog-fish. Bony structures which are first laid down in cartilage are called **cartilage bones,** and most of the bones of higher animals are instances of this mode of formation. Bones which are laid down directly in membrane are called **membrane bones,** and these form a much smaller part of the skeleton of higher animals.

The Vertebral Column or Backbone.—In a dog-fish embryo there is formed from the dorsal wall of the alimentary canal a long gelatinous fibrous rod which lies between the alimentary canal and the nervous system, extending from below the hind part of the brain to the posterior end of the body. This rod is the **notochord,** and is the foundation of the backbone in all vertebrates and the only representative of the backbone in the members of the vertebrate group lower than fishes. In the dog-fish and all higher animals, the notochord is very quickly surrounded by a condensation and concentration of skeleton-forming cells, which give rise to a sheath, such as form the whole skeleton in simpler animals, and it is from this sheath that the actual backbone is formed by a series of segmentally arranged thickenings (Fig. 45). In the dog-fish this sheath of the notochord is cartilaginous, and its anterior portion gives rise to the posterior part of the skull, while in the body it becomes divided transversely into segments which are the **centra**, or bodies of the vertebræ. Above the centra, **neural arches** are formed and surround and protect the nervous tube, while below them, in the hinder part of the body and tail, **hæmal arches** and **ribs** partly enclose the body cavity.

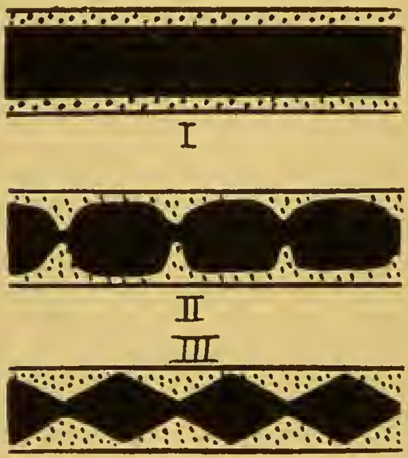

FIG. 45. — Longitudinal vertical section of three stages of development of vertebræ from the cartilaginous sheath of the Notochord. Cartilage, dotted; chord, black. **I.** Continuous sheath, chord unconstricted. **II.** Sheath segmentally thickened, notochord constricted. **III.** Further stage; the segmental thickenings have deepened to form biconcave vertebræ.

By this process of segmentation the backbone, consisting of a series of vertebræ, is formed. The simplest vertebræ are seen in the tail (Fig. 46). Each consists of a **centrum**, through which runs the notochord, a **dorsal arch**, with a dorsal spine above, forming the neural canal through which runs the nerve tube, and a ventral or **hæmal arch**, also with a spine, enclosing the body cavity, which in the region of the tail is minute. Further forward in the body the hæmal arches are not complete; the processes which in the tail meet to form these arches stand out at right-angles to the line of the backbone and are termed **transverse processes**.

To the end of each transverse process a short cartilaginous **rib** is attached.

To understand the structure of the backbone it is necessary to cut transverse, longitudinal, and horizontal sections through various parts of it. It will then be seen that the notochord runs continuously through the whole column, but that it is much constricted where it passes through the centre of each of the centra, and is much expanded between them. Thus, if the column be cut through along the length of two vertebræ, the soft notochord may easily be brushed out, and it can then be seen that the ends of the cartilaginous vertebræ are deeply hollowed out where they meet each other. Such vertebræ are known as **biconcave,** and examples of them are familiar to us all in the backbones of common bony fish like herrings or salmon. Vertebræ which possess biconcave centra are said to be of **amphicœlous** type. The successive centra are united to each other by **intervertebral rings** of connective tissue. The whole of the cartilage of the centra is hardened by deposits of lime, but the deposit is denser towards the inside. In many cartilaginous fish the highly calcified portions of the centra form, in transverse section, a regular, usually X-shaped, pattern.

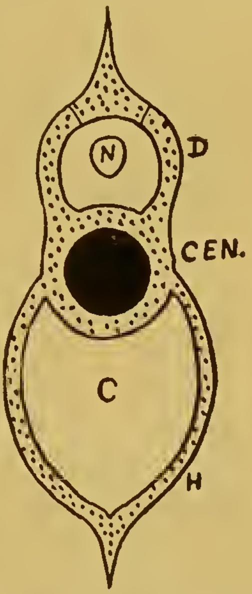

FIG. 46.—Diagram of caudal vertebra. Notochord, black ; cartilage, dotted. **CEN.** Centrum. **D.** Dorsal arch, containing **N,** spinal cord. **H.** Hæmal arch, containing **C,** cœlome.

The **neural arches** (Fig. 47) are complicated. Their bases are formed by the neural processes, blunt pieces projecting from the centra at each side. Firmly fused to each neural process is a **vertebral neural plate,** considerably narrower than the neural process and the centrum, and notched at its posterior border for the passage of the ventral root of the spinal nerve (Fig. 47, *e*). The arches are completed above by short **neural spines** (Fig. 47, *k*). But these are not arranged so as to give one for each centrum, but, with the exception of occasional irregularities, there are two spines for each centrum, and these meet each other opposite the middle of the centrum. Finally, there are irregular hexagonal plates, the **intervertebral neural plates** (Fig. 47, *f*), wedged in between the vertebral neural plates opposite the intervertebral intervals, and which are not fused to the centrum. The posterior border of each is notched for the dorsal roots of the spinal nerves (Fig. 47, *h*).

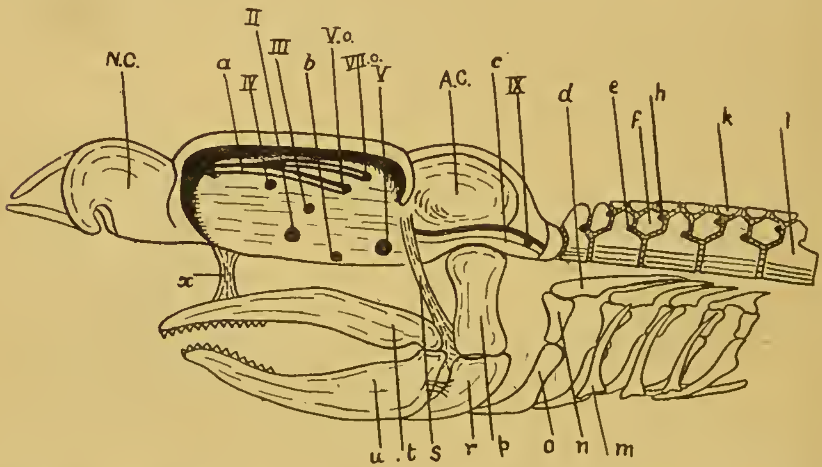

FIG. 47.—Lateral view of skull of dog-fish. **N.C.** Nasal capsule. **A.C.** Auditory capsule. **a.** Orbital grooves lodging ophthalmic branches of fifth and seventh nerves. **b.** Inter-orbital canal. **c.** Post-orbital groove. **f.** Intervertebral neural plate. **k.** Neural spine. **l.** Centrum with vertebral neural plate above it. **d.** Pharyngo-branchial. **m.** Extra-branchial. **n.** Epibranchial. **o.** Ceratobranchial. **p.** Hyomandibular. **r.** Cerato-hyal. **s.** Prespiracular ligament. **t.** Upper jaw. **u.** Lower jaw. **x.** Ethmopalatine ligament. **Nerve Foramina.** **II.** Optic. **III.** Third nerve. **IV.** Fourth nerve. **V.** Main branches of fifth and seventh, and the sixth nerve. **V.o** Ophthalmic branch of fifth nerve. **VII.o** Ophthalmic branch of seventh. **IX.** Ninth nerve. **e.** Ventral root of spinal nerve. **h.** Dorsal root.

The **skull** of the dog-fish remains cartilaginous throughout life. It consists of a shallow oblong **brain case** or box, open behind, where the brain passes into the spinal cord, incomplete and roofed over only by the outer skin in two regions above. This box encloses the brain. The cartilaginous **olfactory capsules,** containing the nasal organs, are fused with it in front on each side of the middle line, and the similar **auditory capsules,** containing the organs of hearing, are fused on to each side of it behind. The **optic capsules** or sclerotic coats of the eyeball lie between the olfactory and auditory capsules on each side, and are not fused with the brain case. The brain case articulates with the vertebral column behind, and the **jaws** and **gill-arches** are suspended below both.

The ventral surface of the skull is formed of a long flat unsegmented plate of cartilage called the **basi-cranium.** The tip of the notochord lies embedded in the posterior part of this. On each side of it there project backwards two rounded **occipital condyles** which articulate with the centrum of the anterior vertebra. In front, the basi-cranium terminates in a narrow pointed bar of cartilage lying between the olfactory capsules.

The dorsal surface of the skull shows in front the thin-walled roofs of the **olfactory capsules.** These are separated by the **internasal septum,** a thin wall of cartilage. The apertures of the nasal capsules are on the ventral surface, but are partly filled by a number of slender nasal cartilages. From each olfactory capsule a bar of cartilage runs forwards, downwards, and inwards, until the two meet at a point with the anterior end of the base of the skull. This three-legged projecting piece of the skull is termed the rostrum. Behind the rostrum and partly between the nasal capsules is the **anterior fontanelle.** This is an incomplete portion of the roof of the cartilaginous brain box. During life it is closed by a delicate connective tissue roof to which the **pineal body** is attached, and which is protected outside only by the outer skin. Behind the nasal capsules the sides of the roof extend as thickened ridges, the **supra-orbital crests,** which overhang the orbits like eaves. On the roof of the skull, behind and to the outer side of the anterior fontanelle, are a pair of small apertures, the foramina for the ophthalmic nerves. Through them pass the ophthalmic branches of the fifth and seventh nerves in their course from the orbit to be distributed to the surface of the olfactory capsules. Behind the anterior fontanelle the surface of the skull widens rather suddenly in the region between the auditory capsules. There is here a depression in which lie two small apertures, the entrances to a canal, the **aqueductus vestibuli,** leading into the internal ear.

Between the nasal and auditory capsules the side of the skull is occupied by the **orbit,** a large oval concavity in which lies the eyeball and its muscles. The orbit is really a large orbital blood sinus. The **orbito-nasal foramen** is a small round hole just within the orbit at its anterior inferior angle ; through it the veins of the fore part of the head and of the snout pass to the orbital sinus.

The aperture of the **inter-orbital canal** is a small round hole, the nearest to the lower border of several lying in the posterior part of the orbit. The canal passes through the base of the skull and by means of it the orbital sinuses of the two sides are in communication. From the hinder end of the orbit a deep **post-orbital** groove passes back near the lower margin of the skull. It lodges a large venous sinus through which the blood from the orbital sinus passes to the anterior cardinal sinus. Under this groove is a large concave depression, the articular surface for the **hyomandibular cartilage.**

To see the posterior face of the skull it must be disarticulated from the vertebral column. The **foramen magnum** is the large round hole by which the brain communicates with the spinal cord. Below it in the middle line, lies the notochord, and on each side of this lie the occipital condyles, two rounded prominences which articulate with the first vertebra. The posterior extremity of the skull corresponds to a vertebra : the lower part, containing the notochord and bearing the condyles, represents the centrum ; the ring of cartilage surrounding the foramen magnum represents the neural arch.

During the development of the skull, holes are left in the cartilage through which the cranial nerves pass out from the brain. The position of these **nerve foramina** is important, and should be studied both in the prepared skull and in connexion with the dissection of the nerves. They are paired, and those of one side only are described.

I. The foramen of the **olfactory nerve** is a large aperture in the posterior wall of the nasal capsule, which, during life, is closed by a fenestrated membrane.

II. The foramen for the **optic nerve** is the most anterior of the large holes in the hinder part of the orbit. It lies near the lower border, almost exactly in the middle of the orbit.

III. The foramen for the **third nerve** is a small hole in the orbit a little above the optic foramen, and half-way between it and the posterior end of the orbit.

IV. The foramen for the **fourth nerve** is a small hole near the dorsal edge of the orbit almost vertically above the optic foramen.

V., VI., and VII. The foramen for the principal branches of the fifth and seventh nerves, and for the sixth nerve, is a large hole in line with the optic foramen, near the posterior edge of the orbit. The ophthalmic branches of the fifth and seventh nerves leave the skull by separate holes ; two grooves run along the upper part of the orbit ; the lower groove ends behind in a small hole which is the foramen for the ophthalmic branch of the fifth nerve ; the upper groove similarly ends in the foramen for the ophthalmic branch of the seventh. These grooves meet in front and terminate in a hole by which the ophthalmic branches leave the orbit to emerge upon the surface of the skull.

VIII. The **auditory** nerve enters the auditory capsule through a hole in its inner wall.

IX. The foramen for the **glossopharyngeal** nerve is at the hinder end of the post-orbital groove.

X. The foramen for the **pneumogastric** or **vagus** nerve is at the side of the foramen magnum, below and to the inner side of the posterior end of the auditory capsule.

THE VISCERAL ARCHES

In the embryo dog-fish, soon after the gill-slits have been formed, a series of cartilaginous hoops or arches encircling the ventral side appear, between them and gives rise to the

jaws, and to the **hyoid** and **branchial arches.** The first arch by segmentation gives rise to the lower and upper jaws. The upper jaw is really an outgrowth from this arch, which becomes constricted off from it. In front of this embryonic first arch is the mouth, and behind it the spiracle. The second arch forms the **hyoid arch,** behind which is the first gill-cleft. Then follow five branchial arches with the remaining four gill-clefts between them, so that each gill-slit has an arch in front and behind.

The first, or **mandibular arch,** is greatly modified in the adult condition. The upper part of the arch at each side is represented by the **prespiracular ligament,** a strong fibrous band containing a nodule of cartilage. This band is attached above to the anterior border of the auditory capsule, and below to a ligament uniting the angles of the upper and lower jaws to the hyomandibular segment of the hyoid arch. The upper jaw or **palato-pterygoid cartilage** is formed of two curved bars which are united by ligament to each other in front, and which are firmly attached by ligaments to the front part of the base of the skull between the orbits and the nasal capsules. The posterior ends of the upper jaw are attached by ligament to the lower jaw and to the hyomandibular arch. The lower parts of the embryonic first bar are represented by two flattened bars of cartilage called **Meckel's cartilages,** which are united by ligament in front and form the lower jaw, and which, for the greater part of their dorsal border, bear teeth. The upper and lower jaws move on each other by rounded articular surfaces. The greater part of the lower border of the upper jaw bears teeth. The dog-fish's skull represents a particular type. It is characterized by the upper jaw not being fused with the skull and by the articulation of both jaws with the hyoid arch behind. Such a type of skull is termed **Hyostylic.**

The second, or **hyoidean arch,** consists of a pair of rods articulating to the skull above, and with their ventral ends connected by a median plate of cartilage. The upper end of each side consists of a stout bar of cartilage, the **hyomandibular,** which articulates with a concave surface on the side of the skull near the hinder end and immediately below the post-orbital groove. This bar is called the **suspensorium,** because it is the chief means by which the jaws are attached to the skull. The outer end of the hyomandibular articulates with the second part of the arch, the **ceratohyal.** This is a slender bar of cartilage running forwards and inwards on the floor of the pharynx. The posterior faces of these two parts of the second arch bear **gill-rays,** cartilaginous bars which support the gills. The **basi-hyal** is a broad ventral plate of cartilage which lies forwards in the middle of the floor of the pharynx and connects the inner and lower ends of the cerato-hyals.

The five succeeding **branchial arches** diminish in size from before backwards. Each is divided into four segments at each side. The **pharyngobranchials** form the dorsal elements. The **epibranchials** come next, and form the outermost pieces of the arches. The **ceratobranchials** form the greater portion of the arches on the ventral surface. The **hypobranchials,** which are turned forwards and connected with the hyoid in the first arch, form the ventral median ends of the arches.

The **basibranchial** is a median plate in the posterior part of the ventral floor of the pharynx, connected with the hypobranchials of the third arch. It represents the fusion of the two pairs of hypobranchials belonging to the fourth and fifth arches into a single cartilage. The pharyngobranchials of the fourth and fifth arches are also fused together, but only partially.

The exact shape and modes of fusion of the different branchial elements in the dog-fish are of no importance unless one is studying the anatomy of a number of different fishes. For while the elements of the branchial arches are similar in most fishes, the details of arrangement and shape differ widely.

Gill-rays are borne by the ceratobranchials, and by all but the hindmost epibranchials.

The **extra-branchials** are three pairs of curved rods lying outside the third, fourth, and fifth branchial arches.

Skeleton of the Fins

The **pectoral girdle** is a flattened hoop of cartilage partly lying on the ventral surface immediately under the heart, its anterior dorsal surface being hollowed out to receive the ventricle. The outer border of each side bears three articular facets closely set together, to which the cartilages of the fin are attached. These articular surfaces divide the girdle into a median ventral portion, which may be called the **coracoid,** and upper or dorsal free ends extending towards the backbone but not meeting it, and which may be called the **scapular** portions. The pointed terminations of these parts may be termed the **supra-scapular** portions.

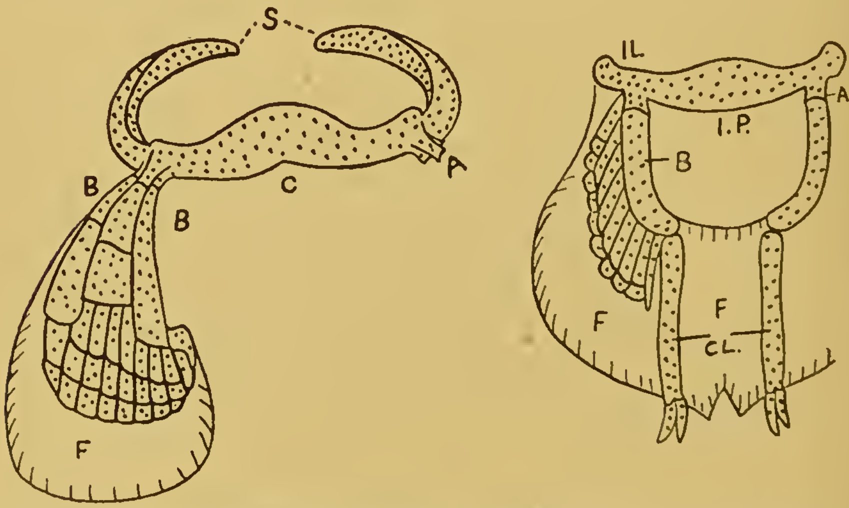

Fig. 48.—Pectoral and pelvic girdles of dog-fish with fins; cartilage dotted. Pectoral girdle: **S.** Scapular region and supra-scapular. **C.** Coracoid regions united ventrally. **A.** Glenoid articulation. **B.** Three basal cartilages. **F.** Fin. Pelvic girdle: **IL.** Iliac region. **I.P.** Ischio-pubic regions united ventrally. **A.** Acetabulum. **B.** Basal cartilage. **CL.** Claspers. **F, F.** Fins.

The skeleton of the fin consists of three **basal cartilages** articulating with the girdle, and a number of closely set cartilaginous **fin-rays** radiating out from the ends of the basal cartilages. The outer border of each fin is supported by closely set horny fibres, called the **dermal fin-rays.** These are embedded between the two layers of the skin and so are not shown in the Figs. Each of the three basal cartilages is named separately. The inner larger one is the **metapterygium,** the middle one is the **mesopterygium,** and the smallest outer cartilage is the **propterygium.**

The **pelvic girdle** is much smaller and simpler than the pectoral girdle, and is placed a short distance in front of the cloaca. It is divided into upper and lower regions by the articular surface for the fins. The upper or **iliac** portions are excessively short, and have hardly any curve upwards. The ventral or **ischio-pubic** portions, like the coracoid regions of the anterior girdle, are fused together in the middle line.

The skeleton of the pelvic fins consists of a stout curved rod, the **basal cartilage** or **basipterygium,** articulating with the girdle at one end and lying along the inner edge of the fin. On its outer surface it bears a number of **cartilaginous fin-rays,** the anterior one or two of which may articulate directly with the pelvic girdle.

In the male a stout jointed rod of cartilage, the skeleton of the **clasper,** articulates with the posterior end of the basal rod of each fin.

Dissection of the Viscera

The dog-fish must be laid on its back on a dissecting board, and pinned down through the fins. The pectoral and pelvic girdles can be felt through the skin, each girdle being situated a short distance in front of the pair of fins attached to it. The abdominal cavity must be opened by a median ventral incision through the skin and underlying muscles, reaching from behind the pectoral girdle to the pelvic girdle. Incisions at right angles to the first cut must be made as close as possible to the posterior margin of the pectoral girdle, and the flaps so formed must be pinned back so as to expose the cavity widely. The pelvic girdle must be cut through in the middle line, and the incision continued, a little to the right of the middle line, to the level of the cloacal aperture. This is the most convenient method of dissecting the dog-fish, but if the student has opportunity it is useful to dissect a second fish from the right or left side, in order to obtain a lateral view of the arrangement and position of the viscera.

The **abdominal cavity,** in which are contained the greater part of the viscera, is the chief division of the cœlome in the adult, and the only part in the posterior division of the body. In front, the cœlome is represented by the **pericardium,** which contains the heart, and the two parts of the cœlome communicate by a small median **pericardio-cœlomic canal.** Posteriorly, the body cavity usually communicates with the exterior by the small **abdominal pores,** but these occasionally are blind sacs, and are not known to be of any physiological importance. The cœlome, then, is practically a closed cavity, and unlike the body cavity of the worm, contains only a very small quantity of serous fluid, devoid of corpuscles. The cavity is lined internally by the **peritoneum,** or **cœlomic epithelium,** a smooth glistening membrane. The viscera in reality are outside the peritoneum ; they bulge into it, as a man leaning against the outside of a tent bulges into the interior of the tent, pushing the canvas wall before him. In the case of the cœlome, however, the bulging goes on so far that the two folds of the peritoneum in which the organs lie are inflected and meet above the organs. Viewed from the inside therefore, when one has opened the cavity as directed, the organs seem suspended in the cœlome by delicate folds. These folds are the inflected portions of the peritoneum and they form the **mesentery,** which is naturally double as it is formed by the applied walls of the peritoneum meeting above the inpushed organs. The blood-vessels also lie outside the cœlome, and their branches to the organs run down between the folds which form the mesentery. The peritoneum is very thin and transparent, and cannot be seen over many of the organs, except in microscopic preparations, while over the genital organs and kidneys it cannot be traced as a separate layer, as a large part of these, as in the case of the earthworm, is apparently formed from the cœlomic wall itself.

The **alimentary canal** is a tube nearly straight from the mouth to the anus. The mouth and pharynx will be considered later. The **œsophagus** is a wide tube leading from the pharynx, and it enters the abdominal cavity at the anterior end. It is suspended in it by the mesentery, which is somewhat perforated.

The anterior end passes at once into the wider U-shaped **stomach,** which is partly concealed by the long yellow-brown **liver.** The proximal limb of the stomach, into which the œsophagus opens, passes nearly to the posterior third of the abdomen, and then bends round sharply to form the shorter, narrower distal limb, which runs forwards and passes into the **intestine,** from which it is separated by a **pyloric** thickening. The intestine runs straight back to the cloaca. The middle and longest part of the intestine is very wide and is marked spirally by blood-vessels which correspond to the line of attachment of the spiral valve, an internal fold. The posterior end is narrower and is called the **rectum.** The intestine should be slit open along its length and washed out. The **spiral valve** is then seen as a membranous fold extending far into the cavity of the intestine and running spirally round it for several turns. Like the typhlosole of the earthworm, it is an arrangement which increases the absorptive and digestive surface of the intestine. In the dog-fish, the intestinal part of the alimentary canal is not differentiated into small and large intestine. The part which it possesses probably corresponds to the colon or large intestine of other forms. The spiral valve functionally plays the part of the small intestine of other fishes. The **bursa enteriana,** or first part of the intestine, receives on its dorsal surface the aperture of the bile duct and on its ventral surface the opening of the pancreatic duct. In the frog and other animals these two ducts open into the duodenum, and the bursa enteriana of the dog-fish may therefore represent this part of the intestinal track of other animals.

The **liver** is a large, solid, yellow-brown organ, consisting of right and left lobes united in front, and extending backwards nearly to the posterior end of the abdomen. Anteriorly, it is attached to the wall of the cœlome by a median suspensory ligament. It is an important organ present in all vertebrates, and has several distinct functions. First, it serves as a storehouse of reserve material which is drawn upon by the body in times of need. The nutritive value of the material stored up in the liver is familiar from the use in medicine of cod-liver oil. Next, it is an organ which secretes nitrogenous waste matter. In this respect it may be compared with the chloragogen cells covering the intestine of the earthworm. In the case of the liver, however, the waste matter is first separated from the blood and then returned to it in the form of urea or of a closely allied, nitrogenous substance, and is finally removed from the body by the kidneys. Thirdly, the liver is a digestive gland which secretes the **bile.**

The **gall-bladder** is a large, thin-walled sac, embedded in the left lobe of the liver near its anterior end. It receives several short ducts from the liver, by which part of the secretion of bile reaches it. The **bile duct** is a stout tube which leaves the gall-bladder, afterwards receiving several short ducts from the lobes of the liver, and running back in the mesentery to enter the bursa enteriana at the commencement of the spiral valve.

The **pancreas** is a whitish, laterally compressed organ occupying the angle between the intestine and the stomach, behind the pylorus. The digestive juice formed in it leaves it by the **pancreatic duct,** which, starting from the ventral side of the pancreas, runs into the ventral wall of the bursa enteriana. About half an inch below where it enters the wall it opens into the cavity of the bursa enteriana, near the attachment of the spiral valve.

The **rectal gland** is a thick-walled, tubular gland lying in the abdominal cavity above the rectum. A narrow duct leaves its posterior end and opens into the rectum. The function of this gland is not known, and it is not found in the higher vertebrates.

The **spleen** is a dark-red body attached to the posterior part of the loop of the stomach, and has a narrow lobe running forwards, closely applied to the distal limbs of the stomach. It is a ductless gland present in all vertebrates.

It receives a very rich supply of blood, and belongs to the lymphatic and vascular system rather than to the alimentary system, one of its functions probably being the destruction of used-up and damaged red corpuscles.

The **respiratory system.** The gills may be examined if they are slit open by cuts extending above and below the external openings of the gill-slits. Each slit leads into a wider and longer cavity, in which the highly vascular gill-lamellæ hang from the walls. The inner end of the cavity communicates with the internal cavity of the pharynx by apertures guarded by cartilaginous processes of the gill-bars which prevent the exit of food with the outgoing water. The gill-lamellæ are folds of the endodermic mucous membrane lining the gill-slits; they are borne on the posterior surface of the hyoid arch and on the anterior and posterior surfaces of the four following arches, but not on the last arch. The anterior wall of the spiracle bears a rudimentary gill, called the **pseudobranch.**

It has been shown experimentally, by means of coloured pigments suspended in water, that the sea-water enters the pharynx not through the mouth, but the spiracles. The water flows out through the gill-slits. The muscular apparatus of the gill-bars is the chief mechanism instrumental in inducing this flow of water through the pharynx. By the contraction of the muscles working upon the branchial bars, the floor and side walls of the pharynx are lternately respectively depressed downwards and inwards and upwards and outwards. During the former movement water is sucked in, and during the latter it is forced out.

The Circulatory System

The **heart** is a muscular tube bent on itself, and lying within the pericardial cavity in the ventral anterior region f the body between the gills. The pericardial cavity is ituated in the floor of the pharynx. The contractions of he heart drive the blood forwards through the anterior end nto arteries which lead to the gills. In these the blood ischarges carbonic acid into the water passing out through the slits, and takes up oxygen. The blood, thus purified, leaves the gills by vessels which meet to form a large median vessel, the **systemic** or **dorsal aorta,** which runs along the body above the alimentary canal, and gives off branches to the different organs. In these, the blood gives up oxygen to the cells of the tissues and receives carbonic acid, and then leaves them by small vessels which meet to form the large thin-walled **venous sinuses,** which lead it back to the heart, entering by the posterior end. The circulatory system is therefore a closed system of tubes through which the impelling propulsions given by the contractions of the heart are sufficient to keep the blood moving. The arteries, or tubes leading from the heart to the gills, and from these through the systemic aorta and its branches to the tissues, are narrow and thick-walled, and therefore very little of the momentum given by the beats of the heart is lost. The veins are much roomier cavities through which the blood percolates more sluggishly on its returning course. In addition to carrying oxygen and carbonic acid and so serving the **respiration** of the tissues, the blood serves the **nutrition** of the tissues. It picks up nutritive materials from the intestine, and allows the cells of the tissues to absorb what they require from these. It also serves **excretion** by receiving nitrogenous waste from the tissues, and carrying it to the liver and the kidneys. The exact share of these organs in the formation of urea, in the case of the dog-fish, is unknown ; but between them, urea is separated from the blood and is discharged from the body by the kidneys. The blood consists of a fluid **plasma** containing **white** and **red corpuscles.** The white corpuscles are amœboid cells, one important function of which is the ingestion and destruction of microbes and other foreign bodies which have found their way into the system. The white corpuscles can pass through the walls of the vessels, and so migrate into the tissues. The red corpuscles are oval, nucleated cells tinged red with hæmoglobin. Their chief function is to carry oxygen from the gills to the tissues. A fuller account of the blood corpuscles will be found in Chapter XXVI.

The pericardial cavity should be opened by an incision in the mid-ventral line in front of the pectoral girdle. Care must be taken not to injure the heart, which lies within it. When it has been opened, the ventral wall should be cut away so as to expose the heart fully, a small piece being also cut out of the middle of the pectoral girdle. The **ventricle,** a thick-walled, muscular and globular sac, is the most ventral and conspicuous part of the heart. Passing forwards from this to the front wall of the pericardium, through which it passes, is the **conus arteriosus,** which narrows as it becomes the **cardiac aorta.** At the junction of the conus and aorta, the latter gives off two pairs of lateral arteries close together. This part of the aorta possibly corresponds to the bulbus arteriosus of the skate and other fishes. In the dog-fish, however, it retains very little, if any, distinctness. The **atrium** is a thin-walled sac occupying the dorsal part of the pericardial cavity, and running forwards from its opening into the ventricle. It overlaps the ventricle at the sides. The **sinus venosus** is the most posterior part of the heart, and is a thin-walled triangular tube, running from the hinder end of the atrium to the posterior wall of the pericardium, through which it passes on either side and opens into the two **Cuvierian veins.** Above the sinus venosus, in the posterior wall of the pericardium, is the opening of the **pericardio-cœlomic canal,** which opens into the abdominal cavity about an inch behind the pericardium on the surface of the œsophagus.

After the blood-vessels have been dissected, the heart should be removed along with the pericardium and part of the floor of the mouth, and cut open, washed out and examined carefully. The ventricle must be opened by cutting away the lower part of its wall; it is seen to be thick-walled and muscular, and to contain only a small globular cavity. The cavity of the conus arteriosus, opened by a ventral slit prolonged from the opening made into the ventricle, is seen to be guarded by a set of three valves near the ventricle, and by another set of three slightly in front. These are arranged so as to prevent the regurgitation of the blood into the ventricle. The opening of the ventricle into the atrium is a transverse slit in the posterior part of the roof of the ventricle, guarded by a two-lipped valve, which prevents blood from passing back again to the atrium during the contraction of the ventricle. The cavity of the atrium must be opened by cutting through the anterior and lateral borders, and turning back the flap thus made of its floor. The walls are thin, and possess radiating muscular bands, which cause the contraction by which the blood is forced into the ventricle. The aperture into the sinus venosus is a vertical slit in the posterior wall; its cavity is spacious, and the walls have a feeble network of muscles. The sinus venosus into which it opens is an elongated triangular sac lying in the posterior part of the pericardium. It has thin, but muscular walls.

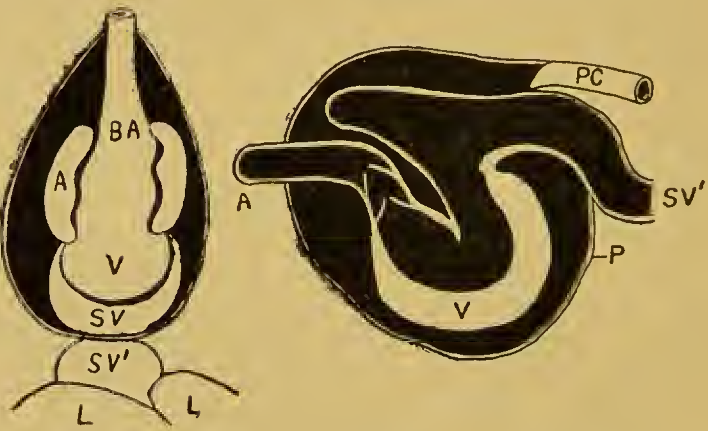

FIG. 49.—Diagram of heart of dog-fish. To the left, ventral view, pericardium opened: pericardial cavity, black. **BA.** Conus arteriosus. **A.** Atrium. **V.** Ventricle. **SV.** Sinus venosus within pericardium. **SV′.** Hepatic sinus. **L.** Liver. To the right, longitudinal vertical section: cavity of pericardium and of heart, black. **P.** Pericardium. **PC.** Canal from pericardium to cœlome. **A.** Conus arteriosus, at the root of which are two pairs of valves; this leads into thick-walled ventricle (**V** wall), which is open above to thin-walled atrium, which communicates behind with sinus venosus (**SV′**), passing outside pericardium.

The **veins** are spacious thin-walled channels forming irregular sinuses rather than vessels. Their dissection can best be commenced by opening the ventral wall of the sinus venosus, washing out the contained blood, passing seekers into the apertures of the Cuvierian veins on each side, and then slitting open their ventral walls and washing out the contained blood. From these the other sinuses can be followed up.

The **hepatic sinuses** open into the sinus venosus by a pair

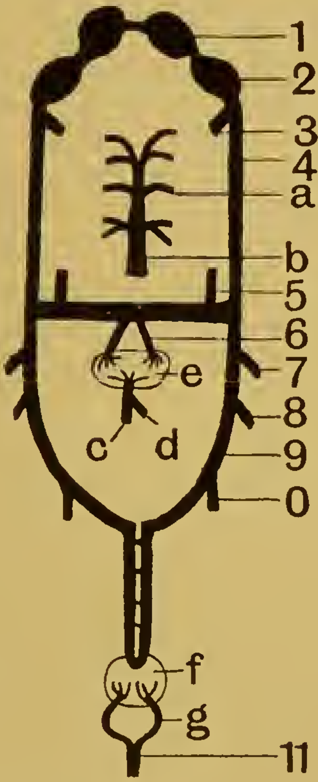

FIG. 50.—Diagram of venous blood channels in dog-fish. 1. Anterior orbital sinus communicating with its fellow of the other side by inter-orbital canal. 2. Post-orbital sinus; this is in reality only a narrow tubular cavity. 3. Hyoid sinus. 4. Anterior cardinal sinus; in reality this is a large, spacious cavity. 5. Inferior jugular sinus. Between the two lie the Cuvierian sinuses, which enter the sinus venosus of the heart. 6. Hepatic sinuses also entering the sinus venosus. 7. Subclavian vein. 8. Lateral line vein. 9. Posterior cardinal sinus; in reality this is a very large and spacious vessel; the two are in close connexion behind and pass back to kidney. 0. Genital sinus. 11. Caudal vein. g. Renal portal vein. f. Kidney. e. Liver. c. Hepatic portal vein. d. Splenic portal vein. b. Cardiac aorta. a. Afferent branchial arteries.

of small apertures near the dorsal part of the posterior wall on each side of the middle line. They return the blood from the liver, and lie close together between the liver and the pericardium.

The **Cuvierian sinuses** or **veins** are the lateral continuations of the sinus venosus. They curve upwards, lying closely applied to the inner side of the posterior branchial arches.

The **inferior jugular sinuses** open one on each side into the middle of the Cuvierian sinus. They run forwards along the outer wall of the pericardium, and in the floor of the mouth.

The great **anterior cardinal sinuses,** one on each side, open into the dorsal end of the Cuvierian sinus by a small hole, guarded by a valve with two flaps. Each extends forwards as a wide, very irregular space lying above the gill arches. At the level of the hyoid arch each receives a **hyoidean sinus,** a narrower venous channel which runs down a groove in the hyo-mandibular cartilage until it meets the jugular sinus.

The **post-orbital sinus** is a narrower tubular channel at each side, which runs from the anterior end of the anterior cardinal sinus, over the spiracle, under the side of the auditory capsule, to open into the very large **orbital sinus,** which surrounds the eye and communicates with its fellow of the other side through the **interorbital canal.**

The **posterior cardinal sinus** of each side extends from the posterior or hinder end of the Cuvierian sinus as a sac, nearly an inch in width, lying first at the side of and then above the alimentary canal. It communicates by many small openings with its fellow of the other side. When they reach the kidneys, the sinuses narrow considerably, and pass backwards between them, receiving numerous **renal veins.** Into each sinus opens first the **subclavian vein,** which returns blood from the region of the pectoral fin ; then the **lateral line vein,** which returns blood from the side of the body wall ; and lastly, the **genital sinus,** which surrounds the genital organs.

The liver and the kidneys are organs which receive not only supplies of arterial blood like all the organs and tissues, but a special supply of blood on account of their special functions. For the latter purpose, both liver and kidneys receive a special supply of blood taken to them by veins. These arrangements are called **portal systems,** and their distinctive feature is that the veins break up into small vessels which ramify through the tissues in question ; whereas veins in other cases do not break up into smaller vessels on their way from the organs to the heart, their special business, so to speak, being to take back the impure blood to the heart without loitering by the way. Portal veins thus have two sets of capillaries, one at either end of the vein. Ordinary or systemic veins have only one set, that at the distal end of the vein.

The **hepatic portal vein** is really the continuation of the main vein of the system. This is called the **anterior mesenteric vein.** It picks up blood from the intestine and receives a **lieno-gastric factor** from the spleen and posterior part of the stomach. It also receives an **anterior gastric factor** from the anterior portions of the stomach. The portal vein breaks up into two large veins which enter, one to each lobe of the liver, and break up into a series of irregular capillaries in the liver.

The blood from the tail is returned by a median **caudal vein,** which runs through the hæmal arches of the vertebral column. Just behind the kidneys it divides into two **renal portal veins,** which, after receiving small veins from the body wall, run along the dorsal surfaces of the right and left kidneys, and gradually break up into vessels which pass into the kidneys.

The arteries, on account of their smaller calibre and thicker walls, can be dissected without opening them ; but it is convenient to inject them from the conus arteriosus, and from the caudal artery.

The **aortic arches,** through which the venous blood is pumped from the conus arteriosus, are termed the **afferent branchial vessels.** The **cardiac aorta,** the forward continuation of the conus arteriosus, runs for about an inch in front of the pericardium in the floor of the pharynx, forking to form the first pair of afferent branchial vessels; each of these divides into two branches. The first runs along the hyoid arch, breaking up into vessels which supply the gill on the posterior face of the hyoid, while the second runs along the outer border of the first branchial arch, giving off branches to the gills lying on the anterior and posterior surfaces of

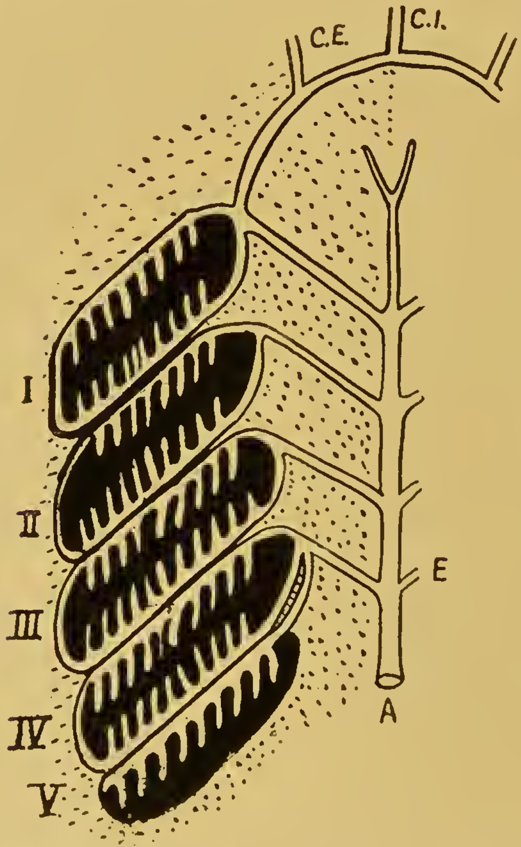

FIG. 51.—Diagram of gill-slits and arteries. I.–V. Gill-cavities: the gill lamella are in white. A. Systemic or dorsal aorta. E. Posterior epibranchial vessel. C.E. External carotid. C.I. Internal carotid artery.

these. The second, third, and fourth afferent vessels run similarly along the second, third, and fourth arches, giving branches to the gills on the anterior and posterior surfaces of these. The last arch, which bears no gill, has no afferent vessel.

The efferent branchial arteries.—A complete arterial loop surrounds each of the four anterior gill-slits, and collects the blood from the gills on their anterior and posterior faces. The posterior slit, which has a gill only on its anterior face, returns its blood by a single vessel, which joins the dorsal end of the fourth loop. From the dorsal ends of the four anterior loops, four **epibranchial arteries** run inwards and backwards, and unite to form the **dorsal aorta,** which runs back along the whole length of the body under the backbone to the root of the tail, where it enters the hæmal arches.

The **carotid artery** of each side arises from the dorsal end of that part of the first loop which comes from the hyoid gill. It runs forwards and inwards along the ventral surface of the skull to the posterior border of the orbit, where it divides into an external carotid which pierces the floor of the orbit and runs forward to supply the jaws and the snout, and an internal carotid which runs inwards and forwards along a groove in the ventral surface of the skull until it meets its fellow of the other side in the middle line, when the common vessel passes through a foramen into the brain.

The **hyoidean artery** runs from the ventral end of the anterior part of the first efferent loop to supply the spiracle, and also sends a small vessel into the brain through a foramen immediately in front of the interorbital foramen in the orbit.

Branches of the dorsal aorta.

The **subclavian artery** of each side leaves the dorsal aorta between the third and fourth epibranchial vessels, and runs backwards and outwards to the pectoral fins.

The **cœliac artery** is a large median vessel which leaves the ventral side of the aorta shortly behind the last pair of epibranchials, and divides into an artery for the stomach and liver and one for the first part of the intestine and the pancreas.

The **anterior mesenteric artery** is a median vessel supplying the intestine and rectum, and arising about two inches behind the cœliac artery.

The **lieno-gastric artery** leaves the aorta immediately behind the mesenteric artery. It supplies the posterior limb of the stomach and the spleen, and in part the pancreas.

The **posterior mesenteric artery** leaves the aorta in front of the anterior end of the rectal gland, which it supplies.

The **parietal arteries** are small, paired vessels which leave the aorta at intervals all along its course and supply the body wall.

The **renal arteries** are small, paired arteries which run from the aorta into the kidneys.

The **iliac arteries** leave the aorta near the posterior end of the abdominal cavity, and one runs to each pelvic fin.

THE RENAL AND REPRODUCTIVE SYSTEMS

In vertebrates, the excretory and reproductive systems are closely connected, and to understand the complicated relations that exist between them, it is necessary to know something of the way in which the two sets of organs are developed. The reproductive glands or gonads, the ovaries in the females, the testes in the males, arise as modified patches of the dorsal wall of the cœlome. In some animals, especially in cases like the common dog-fish, or as in birds, where the eggs, on account of the bulk of food-yolk contained in them, are very large, only one ovary is present in the adult condition ; but typically, there is one pair of testes and one pair of ovaries. The eggs or spermatozoa when ripe would therefore fall into the body cavity. The primitive kidney consists of a series of nephridial tubules arranged segmentally, so that there is one pair for every segment of the body. The other ends of the nephridial tubes open into a longitudinal duct, called the **segmental duct,** which runs back to open to the exterior by the cloaca. Such a condition is represented in Fig. 52, the nephridia only of one side being represented completely. On each nephridium, between the funnel and the opening into the segmental duct, there is a cup-shaped protuberance, or double-walled sac, called the **Malpighian capsule,** in which a tuft of blood-vessels called the **glomerulus** ramify. In the Fig., for the sake of simplicity, the capillary loops of the nephridia are represented as coming only from the aorta, the renal portal system being neglected. Such simple nephridia by their funnels would remove waste matter from the cœlome, and along with this the ripe genital products discharged from the genital glands ; while from the blood in the glomeruli, lodged in the Malpighian capsules, they would extract waste material. In the actual development of vertebrates such a series of paired nephridia leading into a segmental duct occurs ; but this is rapidly followed by that feature of cœlomate development which in Chapter XXIII we called **condensation of segmentation.** The series of nephridia are broken up into three groups, and the original single segmental duct is replaced or divided, so that a separate duct is formed for each group. The middle drawing in Fig. 53 represents this. The anterior group of nephridia is called the **pronephros** or head kidney, and its duct is called the **pronephric duct,** which at a later stage is called the **Müllerian duct.** In the dog-fish the nephridial tubules of the pronephros do not appear. But their duct, the pronephric duct, which, as it frequently is the remains of the original duct, is often called the segmental duct, does appear at each side. The second division of nephridia is called the **mesonephros,** and its duct is the **mesonephric duct,** or from the name of its discoverer, the **Wolffian duct.** The posterior group is called the **metanephros,** or last kidney, and its duct is the **metanephric duct** or **ureter.** In some animals the metanephros is the only functional kidney of the adult, and the metanephric duct is that by which the urine is actually discharged. In

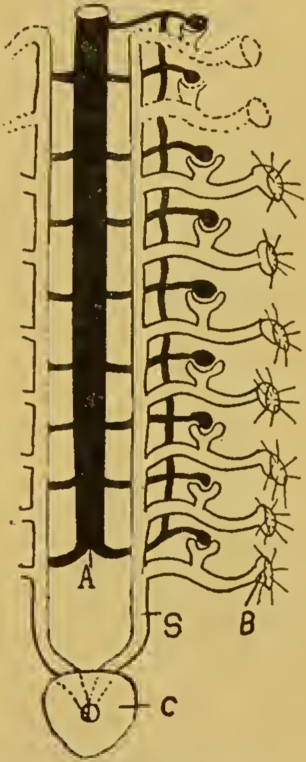

FIG. 52. — Diagram of primitive Kidney. **A.** Systemic aorta which sends branches ramifying in the cup of each nephridium. **B.** Nephridial funnels. **S.** Segmental duct. **C.** Cloaca with apertures of ducts.

most vertebrates these separate ducts appear successively, but while the metanephros forms the kidney of the adult, only those parts of the pronephros and mesonephros are retained which have become specialized into sexual ducts, because they have retained the primitive auxiliary employment of the nephridial funnels as means by which the ripe generative products escape from the cœlome to the exterior. It is very doubtful if the metanephros of the dog-fish is homologous to the definitive kidney or metanephros of the Mammal.

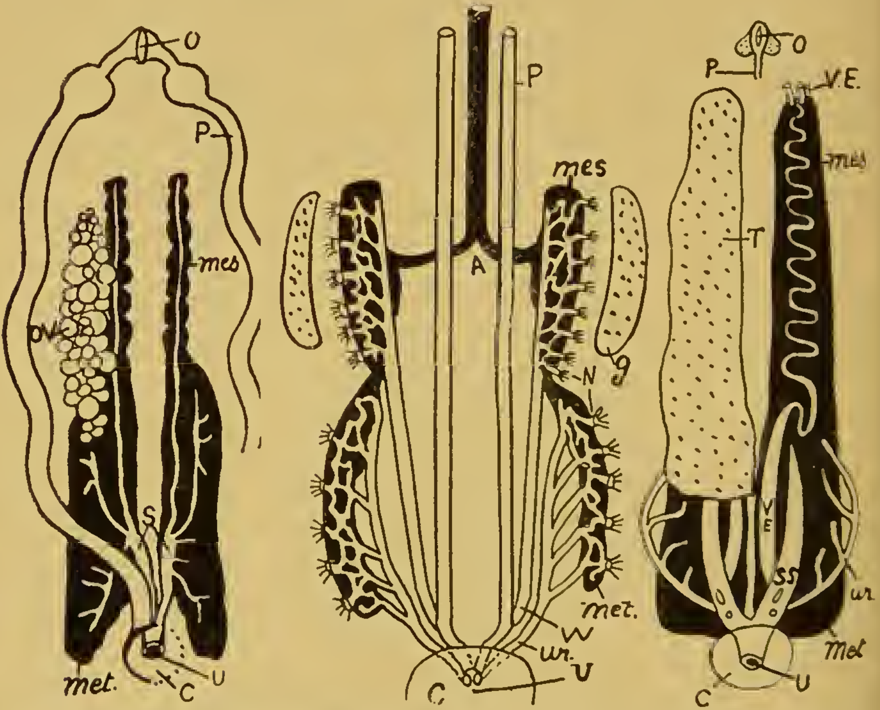

FIG. 53.—Excretory and genital organs of dog-fish. The middle figure is the common type; to the left the female, to the right the male. **A.** Aorta. **Mes.** Mesonephros. **Met.** Metanephros. **P.** Pronephric or Müllerian duct. **W.** Mesonephric or Wolffian duct. **Ur.** Metanephric duct (so called). **G.** Genital organ. **C.** Cloaca. **U.** Urinogenital aperture. In the female, **P,** oviduct with shell gland near the summit. **O.** Common opening of oviducts into cœlome. **OV.** The single ovary. **S.** Urinary sinus into which mesonephric ducts and ureters open. In the male, the testis **(T)** of one side has been removed. **P.** Rudimentary pronephric duct with **O,** opening into cœlome. **V.E.** Vasa efferentia. **V.E.** Vesicula seminalis (mesonephric duct). **SS.** Sperm sac, in the lower end of which are seen the openings of **V.E.** and of **Ur** immediately under the reference letters **SS.**

Its mode of development suggests that it is merely a posterior extension of the mesonephros.

The Adult Female.

The **Ovary** is a single large organ lying in the abdominal cavity suspended from the dorsal wall by a delicate mesentery which is easily torn. The ovary is lobulated on account of the large eggs, in various stages of ripeness, which are contained in it. This single, unpaired condition of the ovary is exceptional. It is in other fishes and most vertebrates, except birds, a paired organ like the testes in the male.

The **oviducts** are the elaborated Müllerian ducts which arise in the course of development by the longitudinal splitting of the segmental ducts. They become enormously expanded as development proceeds. The oviducts are a pair of wide tubes lying on each side of the middle line near the dorsal wall of the cœlome. Their anterior ends meet together in the middle line in front of the liver, and on the ventral side of the junction a ventral slit opens, thus placing their cavity in communication with the abdominal cœlome. Through this the eggs which have fallen from the ovary into the cœlome find their way, and are impregnated by spermatozoa passed into the oviducts by the males during copulation. Nearly a third of its length from the cœlomic opening of each oviduct, there is a large oviducal gland which secretes a horny shell formed around the egg after impregnation. The posterior ends of the oviducts approximate, and open into the cloaca on the dorsal wall, immediately behind the rectum.

In the female the **mesonephros** is rudimentary and consists of a segmented mass of yellow-brown glandular tissue, arranged in patches on the dorsal wall of the abdominal cavity at each side. The patches are arranged so that they correspond roughly to the vertebræ.

The **metanephros** forms the permanent kidney of the adult female. Each is a compact, laterally-compressed, dark-brown mass lying attached to the dorsal wall of the cœlome, one on either side of the middle line. The original segmentally arranged tubules have greatly multiplied in number. In most cases the nephridial funnels into the cœlome have disappeared, although in some cartilaginous fishes microscopic sections through the kidney and the peritoneum show that the apertures of the funnels persist even in the adult. The cup-shaped expansions of the tubules are increased in number, and into them there pass coils of blood-capillaries which also ramify over the parts of the tubules within the kidney. These blood-capillaries, which come both from the renal arteries and from the renal-portal system, together with the tubules and a small amount of supporting connective tissue, form the mass of the solid kidney. The cup-shaped expansions with their contained tufts of blood-vessels form the most characteristic feature in sections of the kidney, and are known as **Malpighian capsules.**

The mesonephric or Wolffian ducts, in the adult female, form a pair of straight tubes running along the whole length of the kidneys on their ventral surfaces. Along the greater part of their anterior length they are exceedingly slender and difficult to find. Their posterior ends are enlarged to form a pair of **urinary sinuses,** which meet together posteriorly and open into the cloaca, on the surface of a small urinary papilla situated in the dorsal wall of the cloaca.

The metanephric ducts form the **ureters** of the adult. There are four or five at each side, and they open by separate apertures into the dorsal wall of the urinary sinus of each side.

The Adult Male.

The male gonads or **Testes** are a pair of soft, whitish, elongated bodies lying on the dorsal wall of the abdominal cavity, and united to each other at their posterior ends. At the anterior end of each testis a number of small tubules, the **vasa efferentia,** leave the testes and pass into the anterior ends of the mesonephros of each side. The spermatozoa, when ripe, instead of being discharged directly into the body cavity, are passed along these ducts to the mesonephros. The pronephros of the adult male, as in the female, is not developed. The Müllerian ducts of each side are quite rudimentary ; at the anterior end of the abdominal cavity, in a situation corresponding to the opening into the body cavity of the female oviducts, there are in the male a couple of small pouch-like sacs in the suspensory ligament of the liver, and behind these a short median strand of tissue represents the anterior parts of the aborted ducts.

The mesonephros of each side forms the front part of the functional kidney of the adult, while the metanephros forms the posterior and larger part of the permanent kidney. A slight constriction usually marks the bounds of the two parts of the kidney, the internal structure of which is similar to that described in the case of the female.

The mesonephric or Wolffian duct of each side is a thick-walled sinuous tube which runs through the whole length of the mesonephros, and into which open the segmentally arranged mesonephric or Wolffian nephridial tubules. Where the mesonephros passes into the metanephros, each Wolffian duct expands into a wide tube corresponding in position to the urinary sinus of the female, although it extends further forwards. This is called the **vesicula seminalis,** and it runs back along the ventral side of the metanephros to open into the urino-genital sinus immediately before that opens into the cloaca.

The **sperm-sac** of each side is a thin-walled sac which has no representative in the female. It lies along the outer side of the vesicula seminalis, and ends blindly in front, nearly at the anterior margin of the metanephros. Posteriorly, each dilates, and by uniting with its fellow of the opposite side forms the **urino-genital sinus.**

The urino-genital sinus receives the openings of the vesicula seminalis and of the ureter, and then it opens into the cloaca by a small pore at the tip of the **urino-genital papilla,** which is situated immediately behind the rectum on the dorsal wall of the cloaca.

There are five **metanephric ducts** at each side. The anterior four unite to form the **ureter,** which is joined by the fifth and then runs along the dorsal surface of the vesicula seminalis to open into the urino-genital sinus.

Thus in the male the mesonephric or Wolffian duct functions both as the ureter of the mesonephros and as a vas deferens by which the genital products, brought to the mesonephros by the vasa efferentia, leave that to reach the exterior. The urino-genital papilla on which the urino-genital sinus opens serves as a common aperture for the escape of excretory and sexual products. In copulation the seminal fluid is directed into the body of the female by grooves running along the dorsal surface of the claspers.

THE NERVOUS SYSTEM

The nervous system of vertebrates is tubular and hollow, and lies along the dorsal surface with an anterior expansion in the head forming the brain. In Fig. 71, which is a longitudinal vertical section through a young vertebrate embryo, a primitive condition of the nervous system is shown. It consists of a hollow tube, open to the blastopore behind, and in front expanded into three bulbs, lying one behind the other, named the three primary vesicles of the brain. These are called the **fore, mid,** and **hind brains.** In the course of the development, the solid parts of the brain and spinal cord are formed by thickenings in the walls of the primitive tube and vesicles, and the cavity remains as a small **central canal** in the spinal cord leading into a series of **ventricles** in the brain. From this central portion the peripheral portion, consisting of nerves growing out in pairs, runs to the tissues and organs.

The anterior part of **the first primary vesicle of the brain** or **fore-brain** grows out to form a large thick-walled mass traversed in the median line by a very shallow and superficial longitudinal constriction. This is called the **prosencephalon**; its two lateral portions on each side of the median furrow correspond to the cerebral hemispheres of the higher animals, and contain the small lateral ventricles. In the dog-fish these are much laterally compressed. From the side near the front grow out the olfactory lobes. The greater part of the posterior portion of the first vesicle forms the **thalamencephalon.** From each side of it, in the course of embryonic development, grows out a bulb which nearly meets the skin of the body As shown in Fig. 72, the anterior wall of each of these lateral bulbs tucks in backwards so that they form cups, carried upon short stalks. These cups will later form the nervous portion of the eyes, and a thickening of the outer skin opposite the mouth of the cup forms the lens of the eye. The dorsal wall of the thalamencephalon gives rise to a stalked bulb, which becomes cup-shaped exactly like the lateral eyes. In the dog-fish, and in most other living vertebrates, this dorsal eye degenerates, and becomes a stalked bulb on the surface of the brain, known as the **pineal body.** But in some living lizards this bulb actually develops into a small structure with the anatomical characters of an eye. In the New Zealand lizard, the *Sphenedon*, or Tuatara, this eye is for a time functional and lies upon the dorsal surface of the skull between the two lateral eyes. It is called the parietal eye. It is not functional in any other animals at the present day, but there is good reason to suppose that in the extinct ancestors of living vertebrates it served as a third eye. The parietal eye, or pineal body as it now exists, is a notable instance of a vestigial organ, that is to say, it is a relic of an organ no longer functional, but which still lingers on in development. Another bulb or sac grows out on the ventral side of the thalamencephalon and becomes what is called the **infundibulum.** On the hind end of this is the **pituitary body,** another organ probably rudimentary, of which the history and function are extremely doubtful.

The walls of **the second primitive vesicle** or **mid-brain** thicken and form the **optic lobes.** The cavity remains as the **iter a tertio ad quartum ventriculum.**

The third primitive vesicle or **hind-brain** becomes the **medulla oblongata.** From its dorsal surface the **cerebellum** arises as a sac-like upgrowth.

The roof of the medulla oblongata is very thin and vascular. In this respect it resembles the thalamencephalon. In both cases the roof is composed of a thin vascular membrane, known as the **choroid plexus.**

The tube forms the **spinal cord,** the walls becoming very thick and the cavity being reduced to a small **central canal.**

Dissection of the brain of the dog-fish is important, because the primitive condition is not much departed from, whereas in higher vertebrates, such as man, complicated bending and folding of the originally straight tube occurs.

Dissection of the nervous system is most conveniently performed upon specimens that have been hardened in spirit. When the viscera have been examined the animal should be put in methylated spirit for a few days, the dorsal wall of the skull having been removed. Then it must be placed on the dissecting board with its dorsal side upwards, and pinned down. The skin must be removed from the dorsal surface of the head, and then, if this has not been done before, the cartilaginous roof of the skull must be sliced away until the brain is exposed. The auditory capsule and the orbit of one side should be left intact. The capsule of the other side must be sliced through while exposing the brain, and the eyelids of the same side dissected away to expose the orbit. As the orbital sinus is opened in this process, the blood clots must be washed away. Then the surface of the brain must be examined : next the eye of one side examined : next the cranial nerves must be dissected ; and lastly the brain and a part of the spinal cord must be removed and examined more fully. In this description the order to be observed in the laboratory will not be followed exactly.

The Dorsal Surface of the Brain

The **prosencephalon** (Fig. 54, P) forms the largest and most anterior part. It is a smooth, somewhat rounded mass lying between the olfactory capsules and the orbits. The separation into lateral hemispheres is marked only by a slight median anterior groove.

The **olfactory lobes** (Fig. 54, I) arise by short stalks from the middle of the sides of the prosencephalon. They are triangular in shape and are closely pressed against the sides of the prosencephalon. In the dog-fish, as in many other predatory fishes which make large use of the sense of smell in hunting, these olfactory lobes are unusually large.

The **thalamencephalon** (Fig. 54, TH) is the narrower portion of the brain immediately behind the anterior part. Its roof is very thin, and the third ventricle can be seen through it.

The **pineal body** (pin) extends forwards from the hinder part of the roof, and terminates in a slightly expanded bulb lying on the surface of the fore-brain. The optic nerves (II), which in a sense represent the stalks of the optic vesicles, may be seen running into the eyeball from under the lower part of the sides of the thalamencephalon.

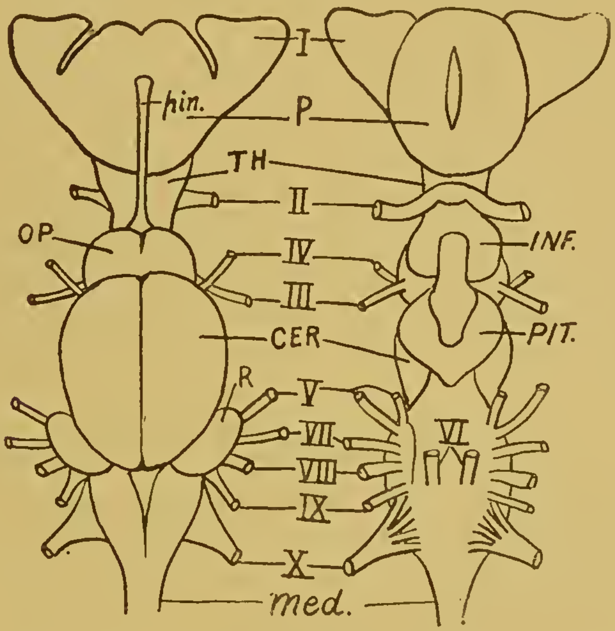

FIG. 54.—Brain of dog-fish. To the right, ventral; to left, dorsal aspect. **I.** Olfactory lobes. **P.** Prosencephalon. **Pin.** Pineal. **TH.** Thalamencephalon. **OP.** Optic lobes. **INF.** Infundibulum. **PIT.** Pituitary. **CER.** Cerebellum. **R.** Restiform bodies. **Med.** Medulla oblongata. (The indicating lines are really too low. They point to the junction of medulla with spinal cord. The medulla is the triangular portion lying above the point touched by the line.) **II.** Optic nerves. **III.** Third nerve. **IV.** Fourth nerve. **V.** Fifth nerve. **VI.** Sixth nerve. **VII.** Seventh nerve. **VIII.** Auditory nerve. **IX.** Glossopharyngeal. **X.** Vagus.

The **optic lobes** (OP) are a pair of rounded expansions which in front partly overlap the thalamencephalon, and behind are partly overlapped by the cerebellum. The fourth pair of nerves (IV) arise from near the middle dorsal line between the optic lobes and the cerebellum.

The **cerebellum** (CER) is an elongated, oval body, which stretches far forwards over the optic lobes and backwards over the medulla oblongata.

The **medulla oblongata** forms the posterior part of the brain. It narrows as it passes back into the spinal cord. The letters MED in the figure are placed at the junction of the medulla with the cord. The roof of the medulla is very thin, and in dissection is frequently torn away, exposing its cavity, the fourth ventricle. The roots of the fifth, seventh, and eighth nerves may be seen coming from its sides in the anterior region. The ninth nerve and the several roots of the tenth nerve may be seen arising from the sides of the medulla in the posterior half, while above these at the anterior end of the medulla there is a large rounded expansion formed by an outfolding of the wall at each side. This is the paired **restiform** body.

THE VENTRAL SURFACE OF THE BRAIN

The examination of this must be deferred until the cranial nerves have been examined.

The prosencephalon and the olfactory lobes appear much as when seen from the dorsal surface, but they pass more directly into the thalamencephalon.

The thalamencephalon, on the greater part of its ventral surface in front, has a curved band, from the ends of which the optic nerves arise. This band is the **optic chiasma,** and is formed by the crossing of the fibres coming from the right and left sides, so that the fibres of the nerve to the right eye come from the left side of the brain and *vice versa*.

The **infundibulum** (inf) is a pair of hollow, oval protuberances (*lobi inferiores*), on the ventral surface of the thalamencephalon, immediately behind the optic chiasma. Attached to the posterior end of the infundibulum is the **pituitary body,** a thin-walled hollow sac. A tubular body, of unknown function, is attached along the middle line of the ventral surface of the pituitary and runs forward to the infundibulum.

The pituitary body, where it lies in contact with the infundibulum, is produced laterally into a pair of highly vascular membranous sacs, called the **sacci vasculosi.**

The roots of the third nerve issue in the middle line from the ventral surface of the thalamencephalon between the infundibulum and the pituitary.

The medulla oblongata is narrow in front and behind. From the ventral surface near the middle line arise the small roots of the sixth nerve, and from the sides arise successively the fifth, seventh, eighth, ninth, and tenth nerves.

The Cavities of the Brain

The original hollows of the vesicles become converted into a series of ventricles opening into each other from behind forwards. The cavity of the medulla is the **fourth ventricle:** the restiform bodies are hollow outgrowths of the dorso-lateral wall, and the cerebellum is an upgrowth of the dorsal wall. The cavity of the mesencephalon, which communicates behind with the fourth ventricle, is narrow, but the optic lobes are hollow protuberances of its dorso-lateral wall. This leads into the cavity of the thalamencephalon, the **third ventricle,** which communicates above with the hollow pineal body, below with the hollow infundibulum. This leads into the cavity of the prosencephalon, which is divided by a median partition into small lateral ventricles which communicate with the hollow olfactory lobes.

The Cranial Nerves

These are of the greatest importance, because they correspond in relative position and partly in function with those in all the higher vertebrates. If we allow for two important changes, the nerves from the brain in the dog-fish and in man are essentially identical. The first difference is this; in man, and in higher vertebrates, the process of cephalization, or condensation of anterior segments to form a head, has proceeded further, and there are two additional pairs of nerves arising from the posterior part of the brain corresponding with the anterior nerves of the spinal cord in the dog-fish. Next, in man the gill-slits and gill-bars, which form so important a part of the anterior region of the dog-fish, are an evanescent occurrence in very early embryonic development, and the distribution, although not the origin, of the cranial nerves is therefore different in many respects. The cranial nerves of the dog-fish should be dissected after the dorsal surface of the brain has been examined. Those of one side only are described.

I. The **olfactory nerves** arise as a bundle of fibres from the anterior end of the olfactory lobes and pass through the membrane separating the brain from the cavity of the nose, by a series of holes. The fibres are distributed to the sensory membrane of the nose.

II. The **optic nerves** run from the chiasma, through the optic foramen into the orbit, and then straight to the eyeball.

III. The **third nerves** or **motor oculi** are slender nerves which arise from the ventral surface of the thalamencephalon, enter the orbit by a special aperture and are distributed to all the muscles of the eye, except the external rectus and superior oblique.

IV. The **fourth nerves** or **pathetici** are slender nerves which arise from the dorsal surface of the mid-brain, enter the orbit by a small aperture above that of the optic nerves and pass to the superior oblique muscle of the eyeball.

V. The **fifth nerves** or **trigeminal** are the most anterior of those leaving the side of the medulla at its broadest part. Before leaving the cavity of the skull it gives off **the ophthalmic** branch, which enters the orbit by a special foramen and runs forward in a groove in the wall of the orbit to an aperture in the anterior superior angle, by which it passes to the skin of the snout, through a canal between the olfactory capsule and the cranium. The main stem of the fifth enters the orbit, sharing a foramen in the posterior part of the orbit with a group of nerves. It then divides into a **maxillary** branch to the skin of the snout and upper jaw, and a **mandibular** branch to the skin and to some of the muscles of the lower jaw.

VI. The **sixth nerves,** which are very slender, arise from the ventral surface of the medulla, enter the orbit with the main branch of the fifth, and pass into the external rectus muscle of the eyeball.

VII. The **seventh** or **facial nerves** leave the side of the medulla next behind the fifth. Their first great branch, the **ophthalmic branch,** arises by a separate root higher up the side of the medulla than the main root. It enters the orbit by a separate foramen above that for the ophthalmic branch of the fifth, runs along the orbit in a groove also above that of the fifth, leaves the orbit along with that branch of the fifth and has a similar distribution. The main stem of the seventh enters the orbit with the main stem of the fifth, and divides into a **palatine nerve,** which runs to the roof of the mouth, and a **post-spiracular, hyoidean,** or **hyomandibular nerve,** which runs to the top of the spiracle and forks there, the anterior and slender limb of the fork splitting up into several short branches, while the posterior large division runs down between the hyoidean and mandibular arches, supplying the skin and muscles of this region.

VIII. The **eighth** or **auditory nerves** leave the side of the medulla behind the seventh, and run straight into the auditory capsule, to be distributed to the sensory parts of the internal ear.

IX. The **ninth** or **glosso-pharyngeal nerves** arise from the side of the medulla next behind the auditory nerve. They run through a canal in the base of the auditory capsule, and leave the skull by a foramen at the end of the post-orbital groove, and then pass out to the summit of the first branchial cleft, over which each one of the pair forks, one branch running along the anterior, the other along the posterior border of the cleft.

X. The **pneumogastric** or **vagus nerves** arise from the side of the medulla by several roots. Within the skull they run backwards a short distance, and emerge at the hind end between the cranium and the auditory capsule. They then run backwards along the floor of the anterior cardinal sinus. From near their roots each one of the pair gives off a nerve which runs along the side of the body to the posterior end, supplying the sense-organs of the lateral line. Next each one gives off four branchial nerves, which fork over the four posterior gill-slits. The main stem is continued as a **visceral branch** which gives off a **cardiac** nerve to the heart and a **gastric** nerve to the stomach.

The **spinal nerves** arise in pairs from the sides of the spinal cord. Each has a **dorsal** or **sensory** root provided with a ganglion and leaving the neural canal by a notch in the posterior border of the intervertebral neural plate, and a **ventral** or **motor** root which consists of several separate bundles rapidly uniting to leave the neural canal by the notch in the posterior border of the vertebral neural plate; it then joins the sensory root.

Connected with the motor roots of the spinal nerves are a series of ganglia which regulate the viscera and are known as the sympathetic system.

Even in the dog-fish the process of cephalization has obscured the primitive simplicity of the cranial nerves to a considerable extent. There is reason to believe that the cranial nerves represent modifications of simple segmental nerves, built on a type resembling that of the spinal nerves, but specially modified in connection with the gill-slits, of which, in the typical vertebrate, there were originally a larger number than five. The typical cranial nerve would consist of a dorsal sensory root with a sensory ganglion and a ventral motor root. But the suppression and alteration of some of the gill-slits, and the formation of mouth and jaws during the process of cephalization, has altered the primitive simplicity.

The olfactory nerve perhaps represents the dorsal sensory part of a segmental nerve of which the ventral motor part has been lost.

The optic nerves are really not cranial nerves at all, but are special outgrowths of the brain.

The third nerve has its sensory part degenerate and formed only by a few fibres to the integument on the side of the orbit. The motor root gives rise to the nerves for the eyeball muscles, The fourth nerve has a few fibres to the conjunctiva, as degenerate sensory part. The motor part is the nerve to the superior oblique muscle.

The fifth and sixth nerves together represent probably a single primitive nerve which has been considerably extended. The first and second branches are chiefly sensory, and represent the sensory part which has been extended to supply missing sensory portions of the third and fourth nerves. The sixth nerve and the third branch of the fifth represent the motor part of the segmental nerve. It is possible, however, that this group represents two segmental nerves.

The seventh also is a complete nerve, of which the ophthalmic branch forms the sensory portion, as in the dog-fish the hyomandibular branch contains both sensory and motor fibres, although in higher animals the motor part alone is retained.

The eighth nerve is the sensory part of a nerve of which the motor branch has been lost.

The ninth nerve has the sensory portion degenerate, while the forks over the anterior gill-cleft represent the motor part.

The tenth nerve represents probably several segmental nerves fused together. The nerve to the lateral line represents the sensory part, while the forks over the gill-clefts and the visceral nerves represent the motor part, though they also contain sensory fibres.

THE SENSE-ORGANS

Sense organs of the mucous canals. These canals, which ramify on the head and along the lateral line, are seen from the exterior as a series of minute apertures from which mucus may be pressed out. Lying in the canals are a set of sense organs consisting of epithelial patches, each connected with the fifth nerve on the head, and with the vagus along the lateral line. Each sense organ is a little bulb of sense cells provided with sense hairs, the bulbs sometimes being covered by a cuticular dome. From the base of the group of cells a nerve fibre runs to the nerve.

They should be examined by cutting and staining transverse sections of portions of the lateral line.

The **nasal organs.** On the ventral surface, shallow, curved grooves lead from the angles of the mouth to the apertures of the nasal capsules. The apertures of the nasal organ lead into a pair of large sacs, which should be cut open and washed out. The sac is lined by mucous membrane thrown into folds and containing groups of sensory cells which are supplied by branches of the olfactory nerve. The nasal organs in elasmobranchs, unlike those of higher animals, are purely sensory, and are unconnected with respiration.

The **eyes.** The eyeball is a hollow sac with a cartilaginous outer coat, the **sclerotic,** to which six muscles run from the walls of the orbit. Four **recti muscles** run from the posterior wall of the orbit and diverge as they approach it. The **rectus superior** is inserted on the dorsal surface, the **rectus inferior** on the ventral surface, the **rectus externus** on the outer and posterior surface, the **rectus internus** on the inner, more anterior surface of the eyeball.

The **oblique muscles** run backwards from the anterior wall of the orbit, the **obliquus superior** being inserted on the dorsal, the **obliquus inferior** on the ventral surface of the eyeball, the insertions being immediately in front of the superior and inferior recti.

The eyeball should be removed, by cutting through the optic nerve and the attachments of the muscles, then opened by cutting it into an inner and outer half with a razor. The halves must be examined under water. The **sclerotic coat** is a thin cartilaginous layer which usually articulates by a knob, near the entrance of the optic nerve, with a corresponding depression in the posterior wall of the orbit. The anterior part of the sclerotic is transparent, and forms the **cornea,** through which light reaches the interior of the ball. It is nearly flat exteriorly, this being a characteristic feature of aquatic animals. The **choroid** is an opaque, black, deeply pigmented layer lying closely applied to the inner side of the sclerotic. It contains a plexus of blood-vessels. The layer turned towards the light is covered by a dense glistening surface, the **tapetum.** The choroid is incomplete in front, leaving a circular area opposite the cornea. This forms the pupil of the eye, and is surrounded by a layer called the **argentea,** filled with clear, glancing crystalline bodies. The **retina** forms the innermost layer of the eyeball. It is a soft, thick layer continuous with the optic nerve behind, which passes through the three coats of the eyeball. The retina is the part of the eye sensitive to light, and in development arises from that outgrowth of the thalamencephalon known as the optic vesicle.

The **lens** is a globular, transparent body occupying the front part of the eyeball. In the dog-fish, as in other aquatic animals, it is more spherical than in terrestrial animals. The cavity of the eyeball behind the lens is filled by a small amount of **vitreous humour,** which, like the lens, is refractive, and aids the lens in focusing the light upon the retina.

The **Ear.**

A primitive ear is an organ for registering vibrations rather than for what we know as sound. In its simplest form, as found in some invertebrate animals, it consists of a pouch of the skin opening to the exterior by a narrow aperture, and provided with cells communicating with a sensory nerve by their inner ends, while on their outer surfaces sensory hairs project into the cavity. The water in which the animals live has access to the cavity from the outside, and in the cavity lie several small particles of stone, which either have come there accidentally or have been formed as limy secretions by the cells of the cavity. Vibrations in the water cause these stones or otoliths in the cavity to stimulate the sensory hairs, and the stimuli are transmitted by the nerves to the nerve centres. In vertebrates the ears first appear as little cavities of this kind open to the exterior, and lined by sensory cells which communicate with nerves. But in subsequent development the auditory pouches sink deep into the cartilage of the skull, and the connection with the exterior in most cases disappears.

The ear of the dog-fish consists of a membranous sac, the **vestibule**, from which arise three **semicircular canals**, contained in hollows of the cartilaginous auditory capsule. It must be examined by gradually paring away the cartilage of the capsule from above downwards. When the skin has been removed from the surface of the capsule there is at once visible a prominent anterior ridge which lodges the anterior canal, and a posterior ridge for the posterior canal. Between these two is a small aperture which leads into a tube, the **aqueductus vestibuli**, which opens into the vestibule. It is not known to have any function in the adult animal, but is the remains of the original invagination of the outer skin which was the starting-point of the ear.

The **vestibule** is a membranous sac lying loosely in the cartilaginous capsule, and partly divided into a lower portion or **sacculus**, and an upper portion or **utriculus** which receives the ends of the semicircular canals. It contains calcareous concretions.

Each **semicircular canal** opens into the utriculus by an expansion, the **ampulla**, then curves through the cartilage, and at its other end again opens into the utriculus. The ampulla of the anterior vertical canal is close to the orbit in the front end of the capsule ; its hinder end opens into a dorsal protuberance about the middle of the utriculus. Into the same protuberance opens the anterior end of the posterior vertical canal, which is much longer, and bends down behind the utriculus until, nearly completing a circle, it enters that by an ampulla at the posterior end. The ampulla of the horizontal canal opens near that of the anterior vertical canal. The horizontal canal then curves outwards in a lateral expansion of the capsule, and, completing the half circle, enters the utricle near the ampulla of the posterior vertical canal. The auditory nerve, which enters the capsule on the side turned to the skull, breaks up into branches which pass to the ampullæ and to the vestibule.

CHAPTER XXV

THE FROG

THE frogs and toads belong to a group of vertebrates known as **Amphibia**, and are specially characterized by the fact that their respiration is effected both by gills and by lungs. In them all the gills appear first. In some of the lower amphibia the gills persist even after the lungs have come into use. In most cases the gills are confined to a larval, fully aquatic stage, the tadpole stage in the frog, while the lungs are the organs of respiration in the adult condition. In the larval condition, and in the adults of some forms like newts, there is a fish-like lateral line with sensory organs, and unpaired dorsal, ventral, and caudal fins. In the frogs and toads these disappear in the adult, and locomotion is effected by jointed fore and hind limbs, which, unlike the paired fins of fishes, are broken up into arms, wrists, and hands, or legs, ankles, and feet, and, like the paired fins, are attached to the pectoral and pelvic girdles.

There are probably several species of frogs native to this country. Of these the most common is the grass frog, *Rana temporaria*, which may be distinguished at once by a large black patch in the temporal region between the eye and the shoulder. *Rana esculenta*, the green water frog, is usually lighter in colour, and is a larger animal. It is not so abundant in this country, or from its more aquatic habits is less often obtained. The colour of the skin in both species is due to the presence of branching cells loaded with pigment. Under the influence of light, and apparently of differences in the colour of the environment, these pigment corpuscles change in shape and distribution, so that the resulting colours more or less correspond to the colours of the environment. These changes are to a certain extent under the influence of the central nervous system, and frogs which have been blinded are stated not to undergo them.

EXTERNAL CHARACTERS

The body is divided into a head, trunk, and limbs. The skin is moist and smooth and devoid of hairs or scales. The mucus, secreted by the skin, is harmless in frogs. In the nearly allied toads it is slightly poisonous and irritant. In both cases it serves as a protection against the attacks of other animals, especially of such marauding insects as ants in the case of the land forms, and against parasitic ticks and growths of hydroids in the aquatic stages. The head is flat and triangular ; at each side it bears the large eyes protected by an upper, fixed eyelid and a lower, transparent, movable eyelid. Behind the eye on each side, in *Rana temporaria* in the middle of the black temporal patch, is a flat circular membrane, stretched tightly over a marginal ring. This is the tympanic membrane.

Apertures. The **mouth** is a wide horizontal slit at the anterior end. The **external nostrils** are a pair of small apertures on the dorsal surface of the head near the anterior end, which during life are constantly being opened and closed. The **cloacal aperture** is a small hole at the posterior end of the trunk, between the legs, but on the dorsal rather than the ventral surface of the body.

Buccal cavity. This must be opened widely and washed out. If the frog has just been killed some of the cells should be scraped off the posterior part of the roof and examined in water under the microscope, that their ciliary motion may be seen.

The **maxillary teeth** are a single row of small teeth lining the edge of the upper jaw ; the lower jaw is devoid of teeth. The **vomerine teeth,** in *Rana esculenta*, are arranged in two small clusters on the roof of the mouth between the internal nasal openings. In *Rana temporaria* they are smaller, and form oblique patches diverging in front, but in the same region.

The **posterior nares** are two small apertures in the roof of the mouth communicating with the exterior through the external nostrils.

The **eustachian** tubes (Fig. 58, *e*) are recesses in the sides of the posterior part of the roof of the mouth. They lead into the cavity under the tympanic membrane.

The eyeballs may be seen projecting into the cavity of the mouth at each side.

The **tongue** is a thin fleshy protuberance attached to the front part of the floor of the mouth, and forked at its extremity. In the condition of rest it lies folded back on the floor of the mouth, but may be shot out forwards.

The **glottis,** by which air passes through the **larynx** into the **lungs,** is a longitudinal slit in the floor of the posterior part of the mouth, and is supported laterally by the **arytenoid cartilages.**

SKELETON

The skeleton of the frog should be studied before the dissection of the viscera is undertaken. The **skeleton of the frog** presents a great advance on that of the dog-fish, as there are in addition to pure cartilage and to cartilage hardened by deposits of calcareous matter a number of **true bones;** especially in the case of the skull many of these bones may be picked off as if they were bony plates plastered upon a cartilaginous framework. The skeleton should be studied in a specimen carefully cleaned and kept in spirit, as well as by the dissection of a fresh specimen.

The **vertebral column.** The vertebræ are fully ossified, and are attached to each other by special **articular processes.** The centra are hollowed out in front, and are convex on their posterior face. Such centra, hollow in front and convex behind, are called **procœlous.** Owing to the complete separation of the vertebræ the notochord is not continuous as in the dog-fish, but within each centrum remains of it persist for a time, surrounded by a delicate sheath.

There are nine separate vertebræ and a long bone behind, the **urostyle,** which is articulated by two facets to the ninth vertebra, and which represents a number of posterior vertebræ fused together. Thus the vertebral column of the frog exhibits not only segmentation, but the partial fusion and telescoping of some of the segments. Each of the vertebræ bears a **dorsal** or **neural arch,** supported upon the centrum. This arch encloses the spinal cord and carries a short backwardly directed **neural spine** above, and at each side a horizontal articular process. Each of the articular processes has two articular facets; the anterior facet or **pre-zygapophysis** looks upwards, the posterior facet or **post-zygapophysis** downwards, and the downward facets of one vertebra overlap the upward facets of the vertebra next behind. Each vertebra, except the first, or **atlas,** has at each side a stout **transverse process,** with which is indistinguishably fused a short vestige of a **rib.** The transverse processes of the last free vertebra are very stout, and at their outer ends articulate with the tips of the iliac bones. It is therefore called the **sacral vertebra.**

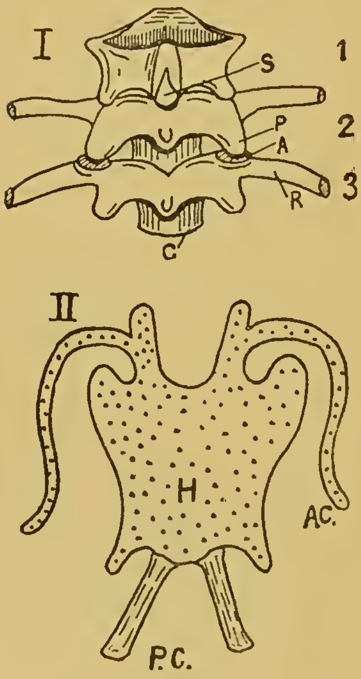

Fig. 55.—I. Three anterior vertebræ of frog from dorsal aspect. **1.** Atlas; **2** and **3,** second and third vertebræ. **S.** Spine. **R.** Ribs. **P.** Posterior down-turned face of articular process. **A.** Anterior upturned face. **C.** Centrum.

II. Hyoid of frog. **H.** Body of hyoid. **A.C.** Anterior cornu. **P.C.** Posterior cornu.

The **urostyle** has a dorsal ridge for the first half of its length, and the neural canal extends into it for about the same distance.

The **skull** of the frog is at first sight very different from that of the dog-fish, but careful study of the tadpole, the fish-like or larval stage of the frog, has shown that in the course of development the skull passes through a **cartilaginous stage** in which it is a shallow box imperfect above, with nasal capsules fused to it in front, and with ear-capsules fused to it behind, leaving a scooped-out hollow at the sides to form orbits for the eyes. Behind and below this primary cranium is a series of gill-arches. The changes from this dog-fish like condition to the adult condition are comparatively simple. The jaws, which in the dog-fish are entirely under the skull, and do not reach the anterior end, are in the frog expanded into great half-hoops, which project outwards beyond the cranium in front and behind. They are therefore so much wider than the skull that the suspensorium for the lower jaw is formed by struts thrown outwards from the region of the auditory capsule to serve as articular supports. These are known as the quadrate cartilages. The upper jaw in front, instead of being merely slung to the base of the skull by ethmopalatine ligaments, is firmly united with the base of the skull and behind it is fused with the auditory capsule. So far, the skull may be compared in shape to a cross-bow. The cartilaginous cranium and the vertebral column behind it represent the line of the stock of the bow. The upper and lower jaws represent the actual bow when bent to a half-hoop, and the struts, running out from the hind end of the auditory capsules to the angles of the jaw, represent the string of the bow.

The **visceral arches**, except the first or **oral arch** which forms the jaws, are united together to form a flat plate, the **hyoid** plate, which lies under and between the lower jaws.

Next, definite cartilage bones are formed in various regions of the cartilaginous skull, and lastly various membrane bones, really formed by the ossification into flat plates of the bony bases of scale-teeth, like those of the dog-fish, are plastered over the underlying structures in various regions.

The description to follow should be compared carefully with a prepared skull; then the skull of a freshly killed frog should be skinned, plunged for a few minutes in nearly boiling water, and carefully cleaned by brushing and scraping. The membrane bones should first be examined and removed, and then the general structure of the cartilage and the cartilage bones studied.

Membrane Bones of the Skull.—The **fronto-parietals** (Fig. 57, F.P) are a pair of elongate flat plates, united by a suture along the middle line, and forming the roof of the greater part of the brain case.

The **nasals** (N) are a pair of flat triangular bones lying behind the nostrils, on the front part of the roof of the skull.

The **squamosals** (S) are a pair of T-shaped bones behind and to the inside of the tympanic membrane. The long arm of the T projects outwards and backwards, and forms the dorsal covering of the suspensorium or quadrate. One end of the cross-limb of the T reaches the posterior edge of the top of the skull, the other projects outwards and forwards.

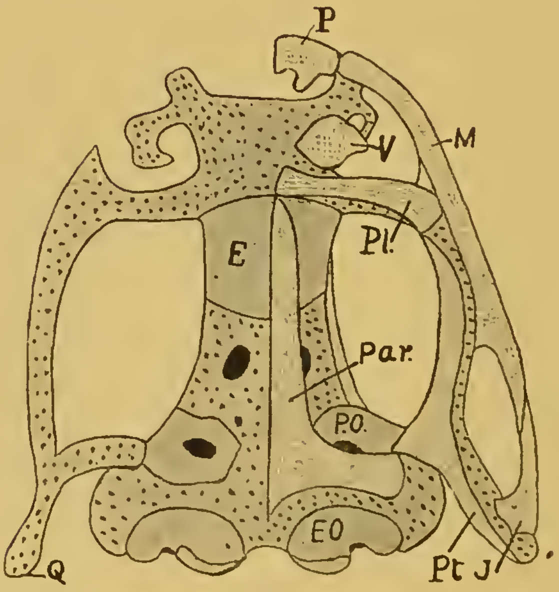

FIG. 56.—Skull of frog (cartilage dotted, membrane bones light, cartilage bones darker). Ventral view: membrane bones of the right side of the skull stripped off. **P.** Premaxilla. **M.** Maxilla. **J.** Quadrato-Jugal. **Pt.** Pterygoid with cartilaginous pterygoid below it. **Pl.** Palatine. **V.** Vomer. **P.O.** Prootic. **Par.** Parasphenoid. **E.O.** Exoccipital. **Q.** Quadrate (suspensorium). **E.** Sphenethmoid. (Partly after Ecker.)

The **premaxillary bones** (P) are two bones united in the middle line, and together forming the anterior part of the upper jaw. Each consists of a lower plate bearing a single row of teeth, and an ascending process which forms a movable articulation with the nasal cartilage.

The **maxillæ** (M) are two elongated curved bones, each of which unites in front with one of the premaxillæ, and so continues the outline of the upper jaw. Behind, the maxillæ unite with the **quadrato-jugals,** which overlap them on the outer side. The maxillæ bear a single row of teeth which are fused to the jaw.

The **quadrato-jugals** (Fig. 56, J) are a pair of slender bones which complete the outline of the upper jaw behind; their broader posterior ends form part of the articular surface for the lower jaw. They have no teeth.

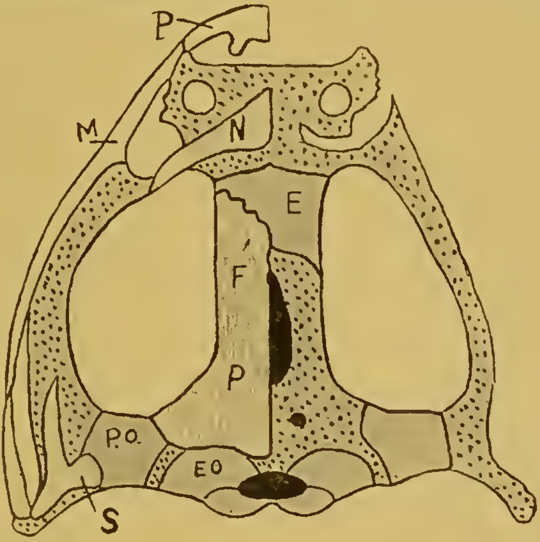

Fig. 57.—Skull of frog (cartilage dotted, membrane bones shaded light, cartilage bones darker). Dorsal view: membrane bones of right side stripped off. **P.** Premaxilla. **M.** Maxilla. **S.** Squamosal. **F.P.** Fronto-parietal (in the figure the **F** and the **P** are widely separated, one lying above the other). **N.** Nasal. **E.** Sphenethmoid. **E.O.** Ex-occipital. **P.O.** Pro-otic. (Partly after Ecker.)

The **parasphenoid** (par) is a dagger-shaped bone which lies on the under surface of the skull, nearly opposite the fronto-parietals. The handle of the dagger is very short, and nearly reaches the lower edge of the foramen magnum. The guard or cross-piece underlaps the auditory capsule of each side. The blade points forwards and ends in the middle line, on a level with the front of the orbits; it supports the base of the brain case.

The **vomers** (Fig. 56, V) are a pair of small bones on the under surface of the front part of the skull, just behind the internal nostrils, and so nearly opposite the nasals. Each bears a small spur which carries teeth.

The **palatines** (Pl) are a pair of small narrow bones on the under surface running at right angles to the long axis of the skull from behind the vomers to the maxillæ.

The **pterygoids** (Fig. 56, Pt) are a pair of curved, three-armed bones partly, but not wholly, of membranous origin. The shortest arm is internal, and ends beside the front edge of the guard of the parasphenoid. The longest arm runs forwards and meets the outer tip of the palatine, and for some distance behind this is in contact with the inner edge of the maxilla, but leaves the maxilla before that meets the quadrato-jugal. The third or outer arm runs from the junction of the inner and anterior arms along the ventral surface of the suspensorium, and its tip forms a small part of the articular surface for the lower jaw.

The lower jaw is formed of two bones ensheathing the primary Meckel's cartilage. The angulosplenial bone at each side forms the inner and lower part of the lower jaw. The **dentary** of each side forms the outer part of the lower jaw in front of the angulosplenial, but the two dentaries do not meet in front. They are separated by a small ossification, called the **Mentomeckelian,** at the point where the two Meckel's cartilages unite at the chin. Notwithstanding their name, the dentaries do not carry teeth in the frog.

When these membrane bones have been stripped off, the true cartilaginous skull becomes visible. It is seen to be an unsegmented cartilaginous tube with the cartilaginous sense capsules fused to it in front and at the sides. It is imperfect above, there being under the fronto-parietals one large anterior fontanelle and two small posterior fontanelles. In three regions the cartilage of the skull is replaced by cartilage bones.

Cartilage and Cartilage Bones of the Skull.—The **exoccipitals** (EO) are two irregular bony masses at the posterior end of the skull, almost completely surrounding the foramen magnum. On their posterior faces they bear the **occipital condyles,** two oval convex processes which articulate with the **atlas** or first vertebra.

The **pro-otics** (PO) are a pair of irregular bones, forming part of the anterior walls and the roof and floor of the auditory capsules.

The **sphenethmoid** (E) or girdle bone is a bony tube forming the anterior end of the cranium ; it extends forwards into the olfactory region. It is provided with a vertical bony partition which separates the cavities for the right and left olfactory lobes of the brain.

The **upper jaw** primarily consists entirely of a cartilaginous arch, the palato-pterygoid cartilage, which secondarily becomes overlaid and extended by the membrane bones which have been described, namely, the palatines, pterygoids, premaxillæ, maxillæ, and quadrato-jugals. The definitive and functional upper jaw is composed of the last three bones, the palatines and pterygoids forming its palate element.

The lower jaw also is primarily a cartilaginous arch overlaid by membrane bones. The upper part of the arch at each side is a rod of cartilage, the **quadrate,** which forms the suspensorium by which the jaw is suspended to the skull. The upper end of this is fused with the auditory capsule, and runs downwards and backwards to the angle of the mouth, where the **quadrato-jugal** meets it. The squamosal and pterygoid bones cover it, and the palato-pterygoid cartilage meets it. The lower part of the arch, that which runs parallel to the upper jaw, at each side forms what is called **Meckel's cartilage.** The inner and lower surface of this is ossified as the **angulosplenial** bone, while another small bone, the **mentomeckelian,** lies at the point where the lower jaws of each side meet in front. Upon its outer surface, at the anterior end, it is covered by the dentary bone.

In the frog the gill-arches are greatly modified, owing to the disappearance of the gill-slits in the adult condition.

The **first** or **mandibular** arch forms the quadrate and the upper and lower jaws.

The tip of the second or **hyoid** arch at each side is separated off to form the columella or ear-bone. This is a rod partly bony, partly cartilaginous, the inner end of which is inserted into the **fenestra ovalis,** a cavity in the outer wall of the auditory capsule. The other end of the columella runs out to be attached to the inner side of the tympanic membrane.

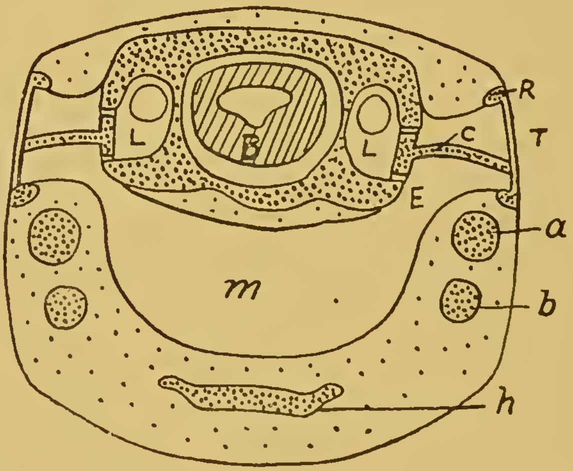

FIG. 58.—Diagrammatic section through head. Skeleton closely dotted. **B.** Brain. **L.** Internal ear with membranous labyrinth (very diagrammatic). **C.** Columella. **T.** Tympanic membrane. **R.** Annulus tympanicus. **E.** Eustachian tube. **m.** Mouth. **h.** Hyoid. **a.** Upper jaw. **b.** Lower jaw.

The rest of the hyoid arch and the remains of the branchial arches are fused into a median ventral plate with anterior and posterior horns, which lies in the floor of the mouth between the lower jaws. The **anterior cornua** are a pair of slender rods of cartilage attached by their lower ends to the median plate, and by their upper ends to the auditory capsule just below the attachment of the columella. The **posterior cornua** are a pair of stout bony processes diverging backwards from the hinder border of the body of the hyoid.

Skeleton of the Limb Girdles.—The **pectoral girdle** consists of two half-loops of cartilage united by ligament at their upper ends to the vertebral column, and by their lower ends to the sternum. Each is divided by the articular cavity for the limb bone into an upper or **scapular** and a lower or **coracoid** portion.

The scapular part consists of a broad, cartilaginous plate above, the **supra-scapula,** and a lower narrower bony portion, the **scapula,** which runs down to the articular cavity. The **coracoid** consists of an anterior and posterior portion separated by the **coracoid foramen.** The anterior part is the **precoracoid,** a slender bar of cartilage which is covered by the **clavicle,** a membrane bone. The posterior part, or **coracoid** proper, is a stout bone, narrow in the middle, and stretching from the scapula to a wide attachment to the sternum. In the mid-ventral line, between the coracoids, are two small rod-like cartilages, which become fused together and calcified. They are called the **epicoracoids.**

The **sternum** is a median flattened portion composed of two segments lying in the ventral body-wall; one is situated in front and the other behind the middle line of the shoulder girdle. The anterior segment consists of a basal slender rod of bone, called the **omosternum,** and of a thin, small, flat plate of cartilage, the **episternum,** attached at its end. The posterior segment, or **sternum proper,** is composed of a broad bony rod, the **sternum,** and of a flattened, expanded plate of cartilage, the **xiphisternum.** Both the episternum and the xiphisternum are bilobed at their free extremity. This bifidity is indicative of the originally paired nature of the sternum. It arises in the tadpole as a pair of cartilaginous plates, which ultimately meet and fuse together along their opposing edges. In some Amphibia this fusion does not occur and the sternum is paired throughout life. Clearly, the sternum of the frog cannot be compared to that of the Mammal. In the latter it is formed from the upturned terminations of the sternal ends of the ribs, which become separately ossified to form a double row of bones, the **sternabræ.** These subsequently fuse and form the sternum.

The **pelvic girdle** of the frog is much modified in association with the jumping habits of the animal. Instead of being at right angles, it makes an acute angle with the backbone, and lies nearly parallel with it. On the outer surface at each side the girdle is divided by the **acetabulum,** the articular surface for the limb, into an upper or **iliac** portion and a lower or **ischio-pubic** portion.

The **ilium** forms the upper portion of the arch at each side. Its anterior end is attached to the broadened transverse process of the **sacrum.** Its posterior end forms part of the acetabulum, and the two ilia meet together at their inner posterior ends to form the iliac symphisis. The ilium is bony.

The ischio-pubic or ventral portion of the girdle consists of a posterior part, the ischium, corresponding to the coracoid, and an anterior portion, the pubes, corresponding to the pre-coracoid. These are, however, closely united together, and with the hinder end of the ilia. The three elements contribute nearly equally to the formation of the acetabulum.

The **ischium** forms the posterior part of the ventral division of the girdle at each side. The ischia form a large part of the acetabulum, and the two are united in the middle line to form the ischial symphysis.

The **pubes** form the anterior portions of the ventral division of the girdle. They are fused in the middle line in the pubic symphysis, and they form a smaller part of the acetabula.

Skeleton of the Limbs.—The limbs of all Vertebrates which possess them are built on the same general plan. The typical structure consists of an upper rod, the **humerus** (in arm) or **femur** (in leg), articulated at the upper end with the girdle. Then follow two parallel rods, the **radius** (arm), or **tibia** (leg), on the side next the body, and the **ulna** (arm) or **fibula** (leg) on the side remote from the body. Next come three rows of small bones, **carpals** (wrist), **tarsals** (ankle). The first row has three bones. In the wrist these are the **radiale,** at the end of the radius, the **intermedium,** and the **ulnare** at the end of the **ulna.** In the ankle they are the **tibiale** at the end of the tibia, the **intermedium,** and the

fibulare at the end of the fibula. The second row consists of one bone, the **centrale**; in the ankle this is sometimes called the **naviculare.** The third row of five bones is called the **distal carpals** in the wrist and **distal tarsals** in the ankle. Then follow the digits of the hand or foot, numbered one to five, beginning with the thumb or great toe, which is on the inside and opposite the radius or tibia. Each digit has a long bone named the **metacarpal** in the hand and **metatarsal** in the foot, and a number of short joints, the **phalanges.**

The arms or legs of all vertebrates are based upon this type. In a very few cases the number of digits is increased, the increase taking place on either side. In most cases the change from the type consists in the reduction of the number of the digits and in the fusion of the bones in some of the rows. In order to compare any animal with the type it should be put in the primitive position. For instance, in the case of man, the primitive position of the limbs is attained when one stoops down on the hands and feet, as if one were licking up water from a pool. Then the elbows project outwards and backwards, the thumbs point forwards, being on the inside of the hands, and the radius also lies on the inside of the arm.

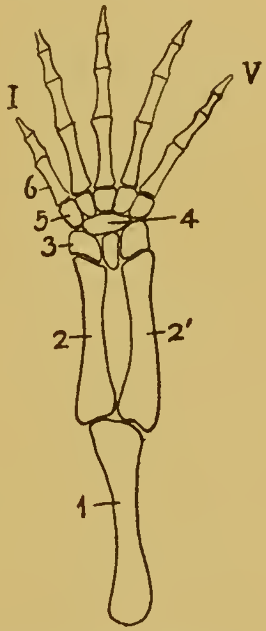

FIG. 59.—Diagram of vertebrate limb: digits I–V. —Leg: 1. Femur. 2. Tibia. 2′. Fibula. 3. Tibiale, intermedium, fibulare. 4. Centrale. 5. Distal tarsals. 6. Metatarsals.—Arm: 1. Humerus. 2. Radius. 2′. Ulna. 3. Radiale, intermedium, ulnare. 4. Centrale. 5. Distal carpals. 6. Metacarpals.

Frog.—Skeleton of the forelimb. 1. **Humerus.** The proximal end or head is enlarged, and articulates with the glenoid cavity of the pectoral girdle. The distal end has a rounded surface, with which the forearm articulates. 2. The **radio-ulna** corresponds to the typical radius and ulna fused into a single bone. Its double composition can be seen internally, where an incomplete median partition divides the bone. The outer side corresponding to the ulna projects behind the articulation with the humerus as the olecranon or elbow process. The three rows of carpals are reduced to two. The first row, or **proximal carpals**, has three bones, the second or distal row has also three, the outer one being very large. There are five metacarpals. The first, corresponding to the thumb, is very small and has no phalanges ; it articulates with the inner distal carpal. In the living condition it does not protrude beyond the skin, and so the frog is said to have no thumb. The second metacarpal is large, and articulates with the second distal carpal. It has two phalanges, and forms the first finger of the frog, which in the male bears a large glandular swelling in the breeding season. The third, fourth, and fifth fingers have all stout metacarpals attached to the large distal carpal, and bear respectively two, three and three phalanges.

Of the three bones in the proximal carpals, two represent the radiale and ulnare of the primitive limb, while the one lying to the thumb side of the radiale is the centrale, which has become displaced. The intermedium is thus absent and it has probably fused, as is known to be the case in other Amphibia, with either the ulnare or radiale. The large distal carpal with which digits 5, 4 and 3 articulate represents three distal carpalia fused together.

Skeleton of the hind limb. The **femur** is the bone of the thigh. Its rounded head fits into the acetabulum of the pelvic girdle, forming the hip-joint. Its broader distal extremity articulates with the bone of the lower leg. The **tibio-fibula,** like the bone of the forearm, is a single structure corresponding to a fused tibia and fibula. As in the case of the radio-ulna, its double composition is manifest in a longitudinal section of the bone.

The ankle also is reduced to two rows of bones. The upper or proximal row consists of two very long bones separated from each other in the middle, touching at the ends. The bone on the inner or tibial side is the **astragalus,** that on the outer side is the **calcaneum,** corresponding to the heel bone of higher animals. The distal row of tarsals consists of two very small bones. There are five digits,

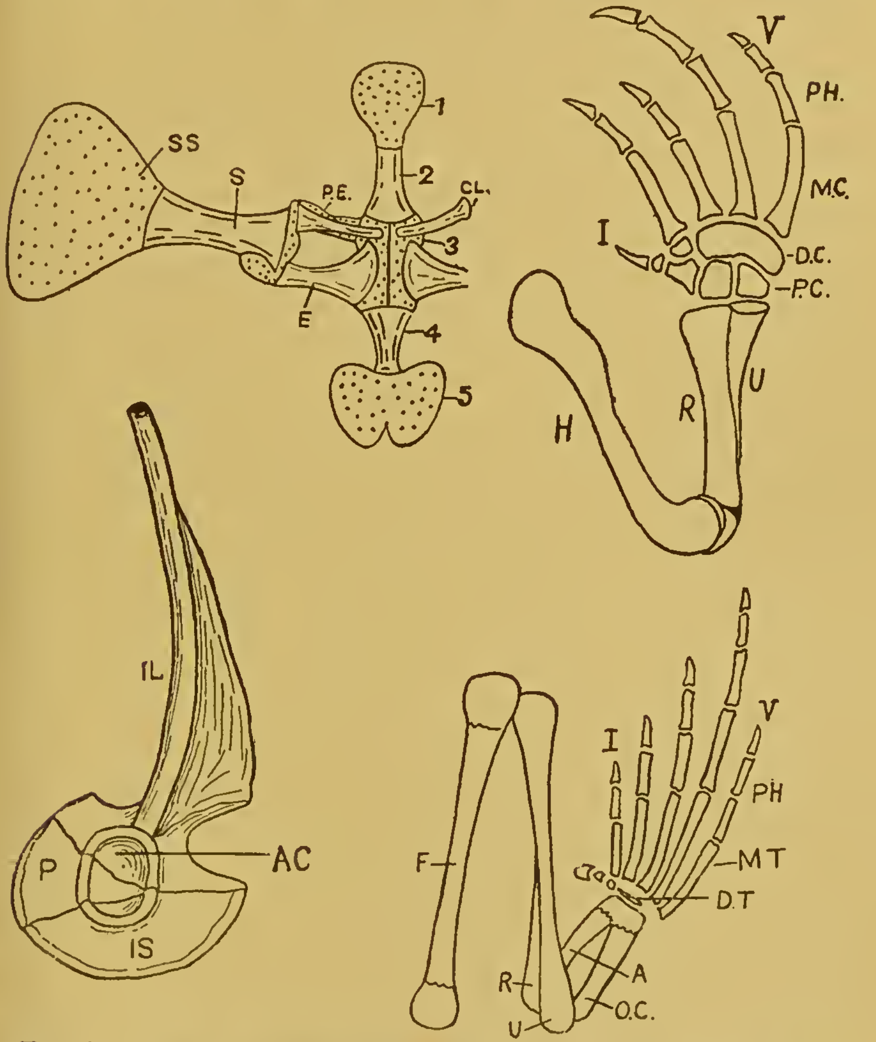

FIG. 60.—Skeleton of girdles and limbs of frog. Upper left-hand figure: Pectoral girdle. **SS.** Supra-scapula. **S.** Scapula. **P.E.** Precoracoid with clavicle (**CL**) overlying it. **E.** Coracoid proper. **1.** Episternum. **2.** Omosternum. **3.** Epicoracoid. **4.** Sternum proper. **5.** Xiphisternum.—Upper right-hand figure: arm and hand of right side, dorsal view. **H.** Humerus. **R.U.** Radio-ulna. **P.C.** Proximal carpals. **D.C.** Distal carpals. **M.C.** Metacarpals. **PH.** Phalanges. **I.** First digit with no phalanges.—Lower left-hand figure: Pelvic girdle of left side. **IL.** Ilium. **P.** Pubis. **IS.** Ischium. **AC.** Acetabulum.—Lower right-hand figure: Leg and foot of right side, dorsal view. **F.** Femur. **R.** Tibio-fibula. **A.** Astragalus. **O.C.** Os calcis = calcaneum. **D.T.** Distal tarsals. **MT.** Metatarsals. **PH.** Phalanges.

number one, the great toe, being on the inner side, and actually being the smallest of the five. Each has a strong **metacarpal** bone which is followed by respectively two, two, three, four, and three phalanges.

In addition there is a **supernumerary** digit, consisting of two short joints, on the inner side more internal than the great toe.

DISSECTION OF THE FROG

This should be performed under water, the frog being laid on its back and fastened to the bottom of the dissecting dish by pins through the limbs. The skin, which is loosely adherent to the underlying parts, being separated from them by the **lymph spaces,** should be dissected off the ventral surface of the body. The position of the pectoral girdle should be determined, and the anterior abdominal vein seen through the body-wall running along the mid-ventral line. The abdominal cavity must be opened by a slit parallel to this vein, as close to it as may be done without injury, and the cut should be continued forwards through the pectoral girdle, which may be cut with scissors, to the jaw, and backwards to the hinder end of the body. Next, the abdominal vein must be carefully separated from the body wall overlying it, and then the body wall at each side should be pinned back, short transverse incisions being made at the posterior end of the original longitudinal incision. The **abdominal cavity,** as in the dog-fish, is the cœlomic cavity, and the viscera are suspended by mesenteries in it exactly in the same fashion, in reality lying outside the cavity. The heart, enclosed in a delicate membranous pericardium, which is a separated part of the cœlome, lies in the anterior region. The **liver** is a large bilobed organ, dark-red in colour, lying partly behind, partly at the sides of the heart. At the sides of the heart and dorsal to the liver, so that they are concealed by it from the ventral surface, are the **lungs,** a pair of thin-walled, lobulated sacs which may be dilated with air by blowing through a fine tube passed through the larynx from the mouth. Immediately behind the liver may be seen the **fat-bodies,** two bright yellow tufts attached to the dorsal wall of the body cavity behind the kidneys, and specially conspicuous in autumn. Behind these, the greater part of the cavity is occupied by the coils of the small intestine, while, at the posterior end, the bladder projects as a transparent thin-walled sac which may be inflated by blowing through a tube passed into the cloaca.

In males, whose sex may be recognised before dissection by the glandular swelling on the index finger, the **testes** appear as a pair of yellow, oval bodies, attached to the dorsal wall of the abdominal cavity. In females, which are usually more bulky in the abdominal region, the greater part of the abdominal viscera are concealed by the **ovaries,** two large masses of small black and white eggs, and the **oviducts,** two much convoluted white tubes with thick walls, lying at the sides of the abdominal cavity.

The **peritoneum** is the lining membrane of the body cavity. It is pigmented in places and, as in the dog-fish, inpushings of its walls, caused by the protrusion of the organs into the cavity, form the mesenteries.

THE ALIMENTARY CANAL

The **œsophagus** is a short wide tube opening into the stomach, which is a curved, dilated tube, not bent to form two limbs as in the dog-fish, and separated from the intestine by a **pyloric constriction.** The **intestine** is much longer and more slender proportionately to the size of the animal, and has no spiral valve, the necessary extent of absorbing surface being given by the increase in length. Posteriorly it passes into the dilated **colon** or large intestine, which opens into the cloaca. The **liver** has a right and left lobe and a large gall-bladder.

The **bile duct** is a slender duct which arises both from the gall-bladder and from the right and left lobes of the liver. It runs through the substance of the **pancreas** to open into the **duodenum,** or first part of the intestine, half-way between the pylorus and a fibrous ligament which fastens the duodenum to a small separate lobe of the liver lying above the gall-bladder.

The **pancreas** is a whitish, irregularly lobed mass which lies between the stomach and the duodenum. It has numerous ducts, too small to be seen in dissection, which open into the bile duct, and so convey the pancreatic secretion to the intestine.

The **spleen** is a small, bright-red organ lying in the mesentery near the anterior end of the rectum.

THE ORGANS OF RESPIRATION AND CIRCULATION

The condition of these organs in the adult frog, and the modified forms of them present in reptiles, birds, and mammals, can be best understood from a consideration of the changes which take place when the tadpole, the fish-like stage, passes into the adult stage. The condition in the tadpole is very similar to that in the dog-fish. At each side of the head six gill-bars appear. The first of these is the mandibular bar, and, as in the dog-fish, this gives rise to the upper and lower jaws. The second is the hyomandibular bar, the succeeding four are branchial bars, one pair less than in the dog-fish. The tip of the hyomandibular bar forms most probably the columella of the ear, while the lower part unites with the remains of the branchial arches to form the hyoid apparatus of the adult frog.

There are five gill-slits. The first, corresponding to the spiracle, never opens to the exterior, and the membrane closing its end is generally believed to become the tympanic membrane, while the cavity leading into the pharyngo-buccal cavity or front part of the alimentary canal forms the eustachian tube. The four succeeding gill-clefts ultimately close up.

While the gill-slits are open, the heart, as in the dog-fish, consists of an S-shaped contractile tube, the dorsal and posterior aperture of which receives blood from the veins, while the ventral and anterior end is continued forward as a truncus arteriosus, which gives rise to four afferent branchial vessels running up the four branchial bars to supply the gills. From these the blood is collected, as in the dog-fish, by four pairs of efferent branchial vessels which unite behind to form a systemic aorta, coursing along the body immediately under the backbone. From the front part of the ventral surface of the alimentary canal a pair of pouches grow out backwards and form the lungs. They are supplied with blood from a special vessel which leaves the efferent vessel of the fourth arch at each side.

The metamorphosis, or change to the adult condition, apparently occurs rather suddenly. The blood, instead of passing through the capillaries in the gills, passes directly from the afferent to the efferent arches by short straight vessels which connect them, and which have been gradually enlarging during the tadpole stage, and, thereupon, the gills and the capillary system shrink up. There are, therefore, at each side four arches corresponding to the afferent and efferent vessels, passing from the truncus arteriosus to the systemic aorta. At the metamorphosis the first or most anterior of these arches give rise to the **carotid** arteries of each side, which already before the metamorphosis have become divided into an external and an internal carotid. The second arches, meeting in the middle line, form the **systemic aorta** of the adult. The third arches disappear. The fourth arches lose their connexion with the systemic aorta, and are continued as branches to the lungs and skin. They form the **pulmo-cutaneous arches** of the adult. Meantime the originally S-shaped heart becomes divided up into chambers by partitions.

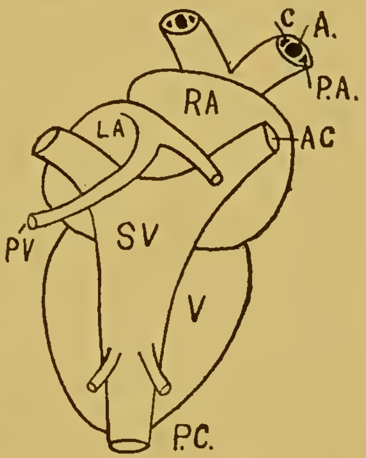

FIG. 61.—Heart of frog: dorsal aspect. **V.** Ventricle. **LA.** Left auricle. **RA.** Right auricle. **SV.** Sinus venosus. **P.C.** Posterior vena cava (post-caval) with hepatic veins. **PV.** Pulmonary veins. **C.** Carotid. **A.** Systemic aorta. **P.A.** Pulmo-cutaneous artery.

The heart of the adult must be examined by opening the pericardium and dissecting it away from the origins of the great vessels. Examination of the interior cavities must be deferred till the vessels have been examined, when the heart may be removed and its chambers slit open under water and washed free from blood.

The **two auricles** occupy the dorsal and anterior part of the heart; they are thin-walled and closely applied to each other and to the ventricle, round which they are wrapped. The **ventricle** is the conical posterior part which is continued forwards as the **truncus arteriosus,** from which the great vessels arise. The **sinus venosus** is a thin-walled sac on the dorsal surface behind the auricles; the **three venæ cavæ** (caval veins) open into it.

When the sinus venosus is cut open, it is seen to lead into the right auricle by a wide opening in its anterior end. This opening is partially guarded by a pair of valves. The venous blood received by the sinus passes into the cavity of the right auricle, from which it is driven, by contraction of the irregular network of muscles in the wall, into the right side of the ventricle. The left auricle is separated from the right auricle by a very thin partition. It receives the oxygenated blood returned from the lungs by the pulmonary veins, and, by contraction of its wall, which, like the right auricle, is provided with a network of muscle, the blood is driven into the left side of the ventricle, through an opening separated from the right auriculo-ventricular opening by a thin septum which hangs down into the cavity of the ventricle. The ventricle has a thick, muscular wall, the inner part of which is spongy. The ventricle opens into the **pylangium,** or first part of the truncus arteriosus, by a circular aperture guarded by three pouch-like valves, the openings of which are turned away from the ventricle so that if blood, pumped into the truncus from the ventricle, attempted to flow back it would run into these pockets, and bulging them out would close the aperture.

The inner wall of the pylangium has a spiral valve attached along its length and hanging freely into the cavity. The pylangium is continued forwards into the **synangium,** which is formed by the united bases of the three arterial trunks. The aperture of the synangium into the pylangium is guarded by three pocket-shaped valves, the openings of which are directed away from the heart. The apertures into the pulmonary arteries are immediately behind these valves. The wide cavity of the synangium forks in front, and is continued as the three arterial arches of each side. A small projecting tongue hangs backwards into the cavity from the angle of the fork, and the small apertures of the carotid arteries lie close together on the under surface of this tongue.

The mechanism by which the streams of mixed blood coming from the ventricle are separated to their proper trunks is apparently very complicated. When the ventricle contracts the truncus arteriosus is still relaxed, and the impure blood from the right side of the heart buoys up the spiral valve and reaches the lower or pulmonary openings. When the contraction has gone on further and the pure blood from the left side is entering it, the truncus begins to contract and the free anterior edge of the spiral valve partly occludes the apertures into the pulmo-cutaneous arches and the purer stream is directed spirally round the valve forwards to the aortic arches and the carotids.

The Venous System. This should be dissected before the arteries. The veins can be distinguished by their thinner walls and larger size, through which the contained blood is visible.

The right and left anterior **venæ cavæ** or **precavals** open into the sides of the sinus venosus, and are formed on each side by the junction of three veins. They are :—

1. The **external jugular** vein, which is itself formed by the junction of the **lingual** vein from the tongue and floor of the mouth, and the **mandibular** vein from the lower jaw.

2. The **innominate** vein, which is formed by the **internal jugular** vein from the interior of the skull, and the **subscapular** vein from the back of the arm and shoulder.

3. The large **subclavian** vein, which is formed by the **musculo-cutaneous** vein from the skin muscles of the side and back, and the **brachial** vein from the arm.

The **posterior vena cava** or **postcaval** is a median vein which runs between the kidneys, from which it returns the blood, to the dorsal part of the liver, through which it passes without breaking up. On its emergence, it is joined by a right and left **hepatic** vein and then enters the posterior end of the sinus venosus. Between the kidneys and liver it receives at each side a vein from the genital organ.

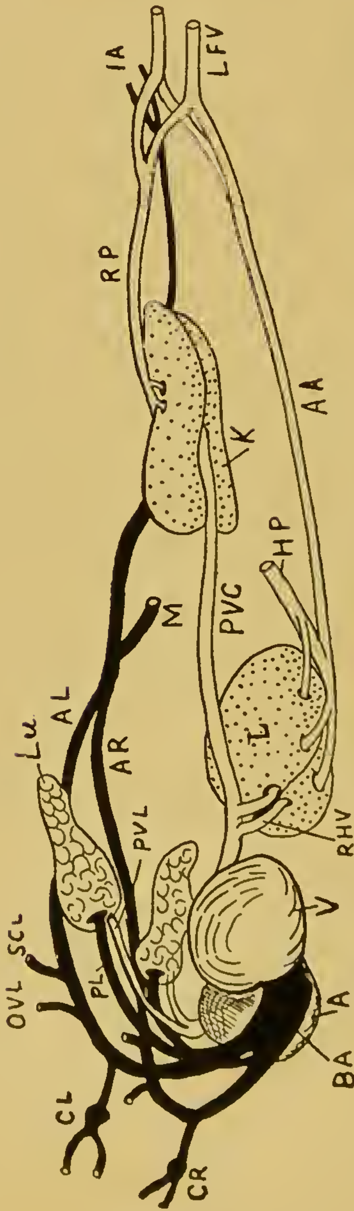

FIG. 62.—Great vessels of frog as seen from the left side. Arteries, black; veins, white. **V.** Ventricle. **A.** Auricle. **BA.** Truncus arteriosus. **Lu.** Lung. **L.** Liver. **K.** Kidney. **CR.** Right common carotid. **CL.** Left common carotid. **PL.** Left pulmonary artery. **OVL.** Left occipito-vertebral artery. **SCL.** Left subclavian artery. **AL.** Left systemic aorta. **AR.** Right systemic aorta. **M.** Cœliaco-mesenteric artery. **IA.** Iliac artery. **PVL.** Left pulmonary vein. **PVC.** Vena cava posterior (post-caval). **HP.** Hepatic portal vein. **AA.** Anterior abdominal vein. **RHV.** Right hepatic vein. **RP.** Renal portal vein. **LFV.** Left femoral vein.

The Renal Portal and **Hepatic Portal Systems.** The greater part of the blood from the hind limbs is returned by the **femoral** and **sciatic** veins on either side. When these reach the pelvic region they unite to form the **renal portal** vein, which runs up along the outer border of each kidney. Just before this union, the femoral vein gives off a **pelvic** branch, which joins its fellow of the other side to form the **anterior abdominal** vein. This runs forward to the level of the liver, where it divides into right and left branches, which break up in the right and left lobes of the liver. The **hepatic portal** vein is a large vessel which returns the blood from the spleen and alimentary canal. It divides into a small branch which breaks up in the left lobe of the liver and a large branch which joins the anterior abdominal vein at the point where it splits into right and left branches.

The renal portal and hepatic portal veins differ from systemic veins in that they have two sets of capillaries, one at their proximal or heart end and the other at the distal end. A systemic vein has only the set at the distal end. The proximal set of the renal portal and hepatic portal veins respectively is in the kidney and the liver and the distal set in the legs and wall of the alimentary canal.

The two **pulmonary** veins return the blood which has been oxygenated in the lungs to the left auricle.

The Arterial System. The **truncus arteriosus** divides into three arches at each side.

The **carotid arch** is the most anterior, and runs forwards for about one-tenth of an inch, when it gives off a small **lingual artery** running in the floor of the pharyngo-buccal cavity to the tongue. Immediately beyond this there is a small globular, spongy expansion of its wall, called the **carotid gland.** Beyond this a small strand of tissue, the **ductus Botalli,** runs back to the systemic arch; it is the remains of the original connexion of the first branchial efferent vessel with the systemic aorta, and usually is impervious, though as an abnormality it may remain open. Beyond the carotid gland, the carotid arch is continued as the **common carotid** artery. It runs forwards by the side of the œsophagus, and divides into the **external carotid**, which supplies the mouth and the orbit, and other parts of the head, and the **internal carotid**, which enters the skull and supplies the brain.

The second division of the truncus at each side forms the **systemic** or **aortic arch**. Each gives off a **laryngeal artery**, several small **œsophageal arteries**, an **occipito-vertebral artery**, and finally a large **subclavian artery** which supplies the shoulder and forelimb. Then the two systemic (aortic) arches meet over the alimentary canal nearly at the anterior level of the kidneys, and form the **systemic** or **dorsal aorta**. From this, immediately after the junction, arises a large median **cœliaco-mesenteric artery** which divides into a **cœliac** branch for the stomach, liver, pancreas, and gall-bladder, and a **mesenteric artery** which divides into anterior and posterior branches for the anterior and posterior parts of the intestine, and a short **splenic branch** for the spleen. While passing between the kidneys, the aorta gives off several paired branches to them and to the genital organs, **lumbar arteries** to the body-wall, and a **hæmorrhoidal** or **posterior mesenteric artery** to the rectum. When it emerges from between the kidneys it divides into a right and left **iliac artery**, each of which, after giving off branches to the bladder and to the ventral body-wall, runs down the leg as the **sciatic artery**.

The **pulmo-cutaneous arch** is the third division of the truncus at each side. At the most anterior part of its course before it bends down to the lung each gives off a slender **cutaneous branch** which is distributed to the outer skin, forming a conspicuous branching system. During winter, while the frog is hibernating in the mud at the bottom of ponds and ditches, this skin-branch is the chief means by which blood is taken to the skin to be oxygenated. The blood is then returned through the cutaneous branches of the musculo-cutaneous vein.

As in the dog-fish, the blood consists of a fluid plasma in which are present white amœboid corpuscles and oval nucleated red corpuscles, the colour of which is due to the presence of hæmoglobin. (For a full description of the structure of the blood, see Chapter XXVI, p. 271).

The Urino-genital System

In the frog, as in the dog-fish, the genital organs appear as a pair of thickenings in the dorsal wall of the cœlome. The excretory organs arise as a pair of **head-kidneys,** each head-kidney or **pronephros** consisting of three nephridia opening by funnels into the anterior part of the cœlome just behind the heart, and leading into a **pronephric** or **segmental duct** which runs down the body, unites near the posterior end with its fellow of the other side, and then opens into the cloaca. Soon after the tadpoles are hatched, the **mesonephros** appears as a number of segmentally arranged nephridia opening into the body cavity by ciliated funnels and into the segmental duct by their other extremities. At the time of the metamorphosis, the head-kidney aborts and the segmental duct splits longitudinally along its anterior portion only, forming an anterior half which sets up a connexion with the peritoneal epithelium, and then extends forwards and eventually opens by an aperture into the cœlome, at the root of the lung. The posterior end of it grows backwards along the posterior part of the segmental duct, until it reaches the cloaca, into which it opens. The new duct thus formed is the **Müllerian duct.** The posterior or mesonephric part of the duct becomes the **ureter** or **Wolffian duct** in both sexes. In the male, the Müllerian ducts disappear, but in the female they enlarge and become elaborated to form the **oviducts.** In the male the Wolffian ducts become the urino-genital ducts, and each develops a seminal vesicle at its posterior end, while in the female they remain as simple urinary ducts.

The Adult Female. The **ovaries** are a pair of black masses lying in folds of the peritoneum in front of the kidneys. In spring and early summer, after the eggs have been discharged, the ovaries are small; in autumn and winter they increase in size, and numbers of ripe eggs are detached from them and occupy the body cavity in masses. Thence they pass through the ciliated oviducts into their large posterior parts, where they are stored until extrusion to the exterior takes place.

The **oviducts** are a pair of much-convoluted thick-walled tubes opening behind into the cloaca by two separate apertures on its dorsal wall, and in front by funnels into the cœlome close to the anterior ends of the lungs. Three regions may be distinguished in each. The **receptive portion,** very small and immediately succeeding the cœlomic aperture, which opens into the cœlome at the root of the lung. This portion is followed by a long, much-convoluted, thick-walled **glandular part.** While the eggs are passing down through this length of the oviduct they become coated in an albuminous coat which answers to the white of egg in a hen's egg. Thus coated, they then pass into the third or terminal part of the oviduct. This is a thin-walled but distensible portion and in it the eggs are stored, one by one, as they pass into it. It is called the **uterine portion.** Towards the end of the breeding season, in the early spring, this part of the oviduct is greatly distended and is full of eggs.

The **kidneys** are a pair of elongate, reddish, flattened bodies lying close to the middle line on each side of the backbone. The ureters are a pair of slender white tubes running from the outer edges of the posterior part of the kidneys to the dorsal wall of the cloaca ; they open immediately behind the oviducts and opposite the opening of the Wolffian bladder which is on the ventral wall of the cloaca. In the living frog the bladder contains fresh water, not excretory products.

The Adult Male. The **testes** are a pair of rounded organs of yellowish colour lying on the ventral surface of the kidneys. The **vasa efferentia** are a number of small tubes leading from the testes to the inner edges of the kidneys, into which they pass when they enter the renal tubules, enabling the spermatozoa to be discharged through the ureters.

The **kidneys** are similar to those of the female.

The **Wolffian duct** or **ureters,** which function also as **vasa deferentia,** or male genital ducts, run from the outer side of the kidney to the dorsal wall of the cloaca, into which they open opposite the opening of the bladder.

The **vesiculæ seminales** are dilatations, one on the outer wall of each vas deferens or ureter of each side, between the kidney and the cloaca.

In both the female and male frog, the gonads (ovary and testis respectively) bear at their anterior ends much-branched, highly vascular masses of fat. These are the fatty bodies or **corpora adiposa.** They serve as a reservoir of food material. In the course of development they are derived by fatty degeneration of the anterior ends of the genital ridges, and therefore represent retrogressive gonadial tissue.

The Nervous System

This is essentially similar to that of the dog-fish, and it should be compared carefully with the figures and notes made while that was being dissected. Owing to the greater difficulty of dissecting the cranial nerves of the frog, the elementary student is recommended not to attempt them until he has thoroughly mastered their arrangement in the dog-fish. The dorsal surface of the brain should be exposed by removing the fronto-parietal bones and continuing the opening by removing the dorsal surface of the occipital region and of the atlas. Examination of the ventral surface must be deferred until the cranial nerves have been dissected.

The divisions of the brain are the same as in the dog-fish. The **olfactory lobes** form the most anterior part. They are fused together in the middle line on the dorsal surface and from their anterior ends arise the **olfactory nerves.**

The **cerebrum** representing the **prosencephalon** of the dog-fish is clearly divided into two **cerebral hemispheres,** which diverge slightly behind.

The **thalamencephalon** is a small part of the brain, partly overlapped by the ends of the cerebral hemispheres in front. Its roof consists of a vascular **choroid plexus** through which the stalk of a small **pineal body** passes. The pineal reaches to the under surface of the skull.

The **mesencephalon** has a pair of very large **optic lobes,** and from the region immediately behind them the **fourth nerves** arise from the dorsal surface.

The **cerebellum** is an exceedingly small transverse band of tissue stretching across the anterior part of the fourth ventricle, immediately behind the optic lobes.

The **medulla oblongata** is relatively large, broad in front, and tapers behind as it passes into the spinal cord. Its cavity or fourth ventricle is, like the third ventricle of the thalamencephalon, roofed over by a thin vascular membrane or choroid plexus, which is usually torn in dissection. From the sides of the medulla the fifth, seventh, eighth, ninth, and tenth nerves may be seen arising by their roots. There are no restiform bodies.

On the ventral surface, the **optic chiasma,** as in the dog-fish, occupies the ventral surface of the thalamencephalon. Behind it is a bilobed **infundibulum** from which the pituitary body extends backwards over the anterior part of the medulla as an elongate, rounded mass. Between the pituitary body and the infundibulum the third nerves arise from the ventral surface of the brain, and the sixth nerves arise from the ventral surface of the anterior part of the medulla.

The **crura cerebri** are two diverging masses of fibres lying in the base of the optic lobes. They are partly hidden by the infundibulum and connect the cerebrum with the medulla and spinal cord.

The cavities of the brain are similar to those in the dog-fish, and receive similar names.

The Peripheral Nervous System. As in the dog-fish the **spinal nerves** arise by dorsal ganglionated roots and ventral motor roots. These unite outside the spinal canal. The **hypoglossal,** or first spinal nerve, runs forward to the muscles of the tongue and floor of the mouth, showing that the process of cephalization has gone on further in the frog than in the dog-fish. A notable condensation of the segmentation of the spinal nerves occurs in two regions. The second and third spinal nerves unite together to form at each side a large **brachial nerve** for the shoulder and arm. The seventh, eighth, ninth, and in part the tenth, spinal nerves similarly unite at each side to form a large **sciatic plexus,** from which is derived the **sciatic nerve,** supplying the hinder limb and a large portion of the posterior region of the body.

The Cranial Nerves.

1. The **olfactory nerve** supplies the nasal organ.

2. The **optic nerve,** as in the dog-fish, supplies the retina of the eyeball.

3, 4, and 6. The **third nerve,** the **fourth nerve,** and the **sixth nerve** have origin, course, and distribution as in the dog-fish, but from their minute size are difficult to dissect in the frog.

5. The **fifth nerve** is the most anterior of those arising from the side of the medulla. It runs forwards within the cranial cavity to the region in front of the auditory capsule. It then expands to form a large **Gasserian ganglion,** and immediately afterwards passes through the skull-wall into the orbit, and divides into two main branches. The first, or **ophthalmic division,** runs along the inner wall of the orbit over the eyeball, and passes in two branches through the walls of the nasal capsule, and is distributed to the skin of the forepart of the head. The second or **maxillo-mandibular** branch runs outwards behind the eyeball and divides into the **maxillary division** to supply the skin of the upper jaw, and the **mandibular division** to supply the skin, and in part the muscles of the lower jaw.

7. The **seventh** or **facial nerve** arises from the side of the medulla next behind the fifth. It runs forward parallel to the fifth nerve to the Gasserian ganglion, with which it is connected, and then emerges into the orbit close behind the fifth. There it divides into a **palatine** branch which runs forwards to the roof of the mouth, and a **hyomandibular** branch which forks under the tympanic membrane, first giving off twigs to that and to the angle of the mouth. The anterior branch of the fork, or **ramus mandibularis,** runs along the floor of the mouth just inside the edge of the lower jaw; the second branch, or **ramus hyoideus,** runs along the floor of the mouth deeper down and supplies the muscles of the hyoid. Comparing the seventh nerve of the frog with that of the dog-fish, it will be noted, the ophthalmic division, the buccal branch and the external mandibular branches are absent.

8. The **auditory nerve** arises immediately behind and apparently but not really fused with the seventh ; it passes at once into the auditory capsule.

9 and 10. The **ninth,** or **glossopharyngeal,** and the **tenth,** the **pneumogastric** or **vagus,** arise together, more posteriorly from the side of the medulla. The two emerge close together from the skull behind the auditory capsule. The ninth divides, and the **anterior** branch, which runs round the posterior end of the auditory capsule, joins the seventh nerve in front of the columella ; this union between the seventh and the ninth nerves occurs throughout the Vertebrata and is known as the **anastomosis of Jacobson.** The **posterior** and larger branch runs downwards and forwards to the pharynx, and then supplies the epithelium and one of the muscles of the tongue. The glossopharyngeal is the sensory, while the hypoglossal is the motor nerve of the tongue.

The tenth nerve enlarges to form a ganglion immediately outside the skull ; it then runs backwards through the body, giving off nerves to the muscles of the back, and several important nerves to the viscera. These are given off from the point where the vagus reaches the pulmonary artery. The **laryngeal,** or recurrent branch of the vagus, loops round the pulmonary artery close to its origin from the truncus, and then runs forwards again, parallel to the vagus until it enters the larynx in the middle line. The **cardiac branch** passes dorsal to the pulmonary artery and reaches the sinus venosus, passing over the precaval vein. The branches of each side unite and pass into the auricular septum. The **pulmonary** branches run along the pulmonary arteries to the lungs. The **gastric** branches, two at each side, pass to the walls of the stomach.

The Sympathetic System. This consists at each side of a **longitudinal ganglionated trunk** extending from the Gasserian ganglion in the skull to the posterior spinal nerve. The ganglia are connected with the spinal nerves and give off numerous networks to the viscera, the chief of which are a **cardiac plexus** over the auricles and the roots of the great vascular trunks and a **solar plexus** over the stomach.

The longitudinal sympathetic cord at each side starts from the Gasserian ganglion. It runs backwards and emerges from the skull with the ninth and tenth nerves, being connected with the ganglion of the vagus. It then runs backwards alongside the vertebral column, following very closely on each side the systemic arterial arch and the dorsal aorta. Along its length it bears ganglia in connexion with each spinal nerve and several in connexion with the tenth spinal nerve. Each ganglion is connected with its corresponding spinal nerve by a very delicate short filament, the **ramus communicans.**

THE SENSE ORGANS

In the tadpole there is a lateral line with definite sense organs, the sensory cells of which are surrounded by projecting cuticular tubes. In the adult these degenerate into patches of mucus-forming cells. But, irregularly placed on the skin, especially on the fingers and toes, there are small touch bodies, each of which consists of a transparent cluster of flattened cells, richly supplied by nerve fibres.

The mucous membrane of the tongue and roof of the mouth contains numerous **taste bodies,** each of which consists of several cells with forked projecting extremities and inner ends in connexion with nerve fibrils.

The **eye** is essentially similar to that of the dog-fish. But the cornea is more curved, and between the cornea and the lens is a small chamber containing aqueous humour. The choroid coat has no tapetum.

The **nasal organs** are proportionately smaller and must be examined by microscopic sections. The cavity is constricted into three divisions, the outer of which communicates with the nostrils, the inner by the internal nares with the buccal cavity.

The Ears. The **internal ear** is essentially similar to that of the dog-fish, but there is no aqueductus vestibuli in the adult. With the disappearance of the aqueductus vestibuli, the ductus endolymphaticus and saccus endolymphaticus no longer run towards the exterior to open there upon the skin.

They pass instead to the cranial cavity, where a strange condition of the saccus endolymphaticus originates. Here it lies between the brain and the cranial wall, and is continued backwards along the whole length of the neural canal dorsal to the spinal cord as an unpaired tube, and giving off paired sac-like outgrowths which pass through the inter-vertebral foramina to lie upon the ganglia of the spinal nerves. They are easily recognized by the opaque white colour of the calcareous concretions which they contain. The sacculus of the frog not only gives off a lagena as in the dog-fish, but another small oval-like sac, the **pars basilaris cochleæ.** It foreshadows the formation of the basilar membrane of the cochlea of higher forms. In the dog-fish the auditory capsule is separated from the outer world only by the outer skin. In the frog the capsule is more deeply sunk in the side of the head. The upper part of the hyomandibular gill-cleft, which opens below into the mouth as the Eustachian tube and which is closed over by the tympanic membrane, forms a middle or accessory auditory chamber. The inner wall of this is formed by the outer wall of the auditory capsule, and in this there is a hole into which the head of the columella fits. The columella stretches across to the tympanic membrane and its outer end is attached to that. Thus vibrations of the tympanum are transmitted along the columella and by its inner end are transmitted to the inner ear. In higher animals this middle chamber in turn is sunk into the side of the head and so the tympanic membrane is at the bottom of a cavity, the external auditory meatus, which is surrounded by the shell of the ear. Thus in man, the frog and the dog-fish, three stages of elaboration are shown.

CHAPTER XXVI

HISTOLOGY

THE Metazoa or multicellular animals, complex though they may be in their structure, nevertheless arise from a single cell, the fertilized ovum. From it, by many cell-divisions, divers kinds of tissues are ultimately formed. Collectively, these tissues compose the organism ; they are bound together in different ways and build up the organs—stomach, heart, liver, lungs, brain, and so on—which are the grosser and visible signs of organization in the individual. These organs can for the most part be seen and their relationships made out by means of ordinary dissections. Their systematic description and study constitutes **Anatomy**. Anatomical studies therefore simply deal with the gross structure of the organism. It may be defined as the " **Science of Organs.**" But the study of the tissues which build up the organs cannot be adequately followed without the aid of the microscope and of special methods of preparing them for microscopical investigation. For the tissues are composed of cells, which, with but few exceptions, are microscopical in size. Moreover, there are divers kinds of tissues, and each is characterized by cells of special form, size, and nature. The study of tissue therefore involves a careful examination of the form, size, nature, and relationship of the cells composing it. **Histology**, the name applied to this study, is therefore the " **Science of Tissue.**"

Although a metazoan is thus composed of numerous and divers tissues, their number is limited, and they can be classified together in a very few primary groups. The tissues which fall within these groups we may call the **Fundamental** or **Simple Tissues.** These are built together in different ways to form the various organs of the body. Thus the brain, which is an organ, is not only composed of nervous tissue, but of a delicate connective tissue called neuroglia and of blood and lymph vessels, through which flow blood and lymph—both the two latter being, in a morphological sense, also tissues. Similarly, the stomach, an organ of digestion, is composed of the following primary or fundamental tissues: epithelium, lymphoid tissue (a variety of connective tissue lodging lymphocytes), nervous tissue, muscular tissue, fibrous tissue, blood and lymph vessels.

The **Primary, Fundamental**, or **Simple Tissues** may be classified under the five following headings:—

(1) **Blood.**
(2) **Epithelial Tissues.**
(3) **Connective Tissues.**
(4) **Muscular Tissues.**
(5) **Nervous Tissues.**

These and their various subdivisions we shall proceed to study in the order described.

THE BLOOD TISSUE

The blood is a moving tissue; its component cells are free and are carried round in a circulating fluid from point to point in the body. The liquid part of the blood is named the **plasma**. It consists chiefly of water with some proteins and mineral salts in solution. The chief proteins are serum-albumin, paraglobulin (sometimes called serum-globulin), and fibrinogen. The chief salts are the phosphates of sodium, calcium, and magnesium, the chlorides of potassium and sodium, and the sulphate of potassium. Certain other substances, such as fats, various extractives (more or less simple combinations of nitrogen), glucose (partly free, partly in combination), and gases are also present in small quantities.

The functions of the blood are highly important. All living tissues are continually undergoing chemical disintegration and integration. The products of their destructive activity must be carried away from them and new material brought to them for their reconstruction. The blood fulfils these double and related functions. By means of its plasma it also carries digested food material from the alimentary tract to the liver, and thence to the heart, whence it is then carried to the tissues. The blood coming from the organs of respiration (lungs or gills) carries a store of oxygen to the tissues for the purpose of their respiration. This transference of oxygen is attained chiefly through the agency of the hæmoglobin contained in the red corpuscles. The tissues making use of the digested food substances and oxygen build up their protoplasm. Protoplasm is never stable, for the advent of oxygen to it ushers in a series of destructive or oxidative processes, which result in the formation of waste products. These must be removed from the tissues as soon as possible, and it is the plasma of the blood which chiefly effects this end. It carries the waste materials to the organs of excretion ; the carbon dioxide is then excreted by the lungs, gills, and skin,[1] and the urea and other nitrogenous matters by the kidneys or nephridia.

The conveyance of oxygen from the air-sacs in the lungs, or from the gills in the fish and the larvæ (tadpoles) of the frog and other Amphibia, to the tissues of the body is a special function performed by a special mechanism. The red corpuscles are the carriers of the oxygen, and they accomplish this in virtue of a red colouring substance called **hæmoglobin**. This body is an iron-containing protein. Its chemical constitution is very complex. It is a compound of about 96 per cent. of a protein, globulin, with about 4 per cent. of a brown pigment, hæmatin. It is this latter which contains the iron and has the chemical formula $C_{34}H_{35}N_4F_2O_5$. Hæmoglobin can be crystallized from solution. Its aqueous solution is not diffusible and it easily undergoes decomposition.

Hæmoglobin possesses the power of forming a loose chemical combination with oxygen, when the pressure of this gas in the medium in which the hæmoglobin is lodged is high, and of yielding up the oxygen when the oxygen pressure is low and the carbon-dioxide pressure is high. Hæmoglobin which has taken up oxygen is called oxyhæmoglobin. But when it has given up its oxygen it is then known as reduced hæmoglobin.

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[1] The skin functions as a respiratory organ in certain special cases, frog and earthworm, &c.

Oxyhæmoglobin is formed in the organs of respiration and is then carried by the circulation of the blood and its corpuscles to the tissues of the body. The latter are relatively rich in CO_2 and poor in oxygen, and it is among them that the oxyhæmoglobin is converted to reduced hæmoglobin by there giving up its oxygen. When it again reaches the respiratory organs, it is once more reconverted to oxyhæmoglobin, and thus, in regularly alternating phases, it goes on so long as life lasts.

The carbon dioxide excreted by the tissues is in part taken into solution in the plasma, in part it forms an association with some of the proteins of the plasma, and in part it also forms a chemical combination with the sodium carbonate of the plasma, as sodium bicarbonate. It is also possible that a certain part of it may form an association with the reduced hæmoglobin. The dissociation of the CO_2 from the proteins of the plasma appears in some way to depend upon the influence of the corpuscles. The passage of the CO_2 from the blood to the air-sacs of the lungs is doubtless effected partly by the physical process of diffusion and partly perhaps by the secretory activity of the cells of the pulmonary epithelium. The same fundamental processes are at work in aquatic as in terrestrial or air-breathing forms.

In all Vertebrata, with the exception of *Leptocephalus*,[1] the hæmoglobin is carried in the red corpuscles. It is lodged in the microscopic meshes of the stroma of the corpuscles. In the earthworm and some other worms too, the hæmoglobin is dissolved in the plasma of the blood. The corpuscles in these animals are all colourless. In some molluscs and arthropods, the plasma contains hæmocyanine, a pigment which plays the same part as the hæmoglobin. It imparts a

[1] In this fish, all the corpuscles are colourless.

barely perceptible bluish tinge to the blood when seen in quantity.

The Corpuscles

In the Vertebrata the corpuscles of the blood may be classed into two groups: namely, the red and the colourless. The red are much the more numerous; they occur, in most mammals, in the ratio of about 500 red to 1 colourless.

Red Corpuscles

In fishes, amphibia, reptiles, and birds the red blood corpuscles are relatively large, oval, biconvex, nucleated discs (Plate IV, Figs. 2 and 3). In the frog they measure in their long axis about 0·022 mm. and in their short axis 0·015 mm. But in mammals the red corpuscles are much smaller, namely, 0·0075 mm. in diameter. They are round, biconcave, or plano-concave, non-nucleated discs (Plate IV, Fig. 1).

All red corpuscles are invested externally by an extremely thin film, not possible to see in mammalian blood, but in amphibian blood it can be demonstrated by suitable staining re-agents. Internally, the red corpuscle is composed of a microscopic meshwork called the stroma (s). This forms the body of the cell and it lodges the hæmoglobin in solution. The nucleus (n) of red corpuscles (those of the mammal excepted, where it is absent) is prominent and oval, and in some cases a distinct nuclear skein is present (Plate IV, Figs. 2, 3 n). The nucleus is devoid of hæmoglobin.

The red corpuscles are elastic and can bend or lengthen when passing through narrow capillaries or turning a corner.

The White or Colourless Corpuscles.

There are many sorts of colourless corpuscles. We shall only consider the chief kinds here. They are sometimes spoken of as **leucocytes.** Some varieties are markedly amœboid in their habits, and these are distinguished from others which are less so, by naming them the **phagocytes.**

Some of the leucocytes are coarsely granular (Plate IV, Fig. 5) and others are finely granular (Fig. 4). In some the granules stain with acid stains such as eosin, and in others only with basic stains such as methyl green and methylene blue. Others stain with both kinds of stains, and yet others will only stain with neutral stains.

Some leucocytes have a fragmented or lobed or multiple nucleus (Figs. 4 and 7), and others only one (Figs. 6, 8 and 9).

The leucocytes are largely classified by the chemical or staining reaction of their granules, the condition of their nucleus, and the degree of their amœboid activity. We may consider the following varieties :—

(1) Polymorphonuclear or polynuclear corpuscles.
(2) Eosinophil or oxyphile corpuscles.
(3) Basophil corpuscles.
(4) Macrocytes or hyaline corpuscles.
(5) Lymphocytes.

The **polynuclear corpuscles** (Plate IV, Fig. 4) constitute about 70 per cent. of the leucocytes of the blood. They are relatively large and measure 0·01 mm., the red corpuscles being only about 0·0075 mm. The protoplasm stains readily with acid stains while the granules, which are very fine, stain only with neutral stains. The characteristic feature of these corpuscles is the condition of their nucleus (n). There may be apparently two, three, or even five nuclei present. But careful examination reveals the fact that these are joined to each other by strands of nuclear matter. In some of these corpuscles there is only a single nucleus, but it is lobed into three or more divisions. It is clear therefore that the nucleus of the polynuclear corpuscles have the capacity of breaking up or fragmenting, each fragment retaining its connexion with the other by filaments of its own material. The corpuscles are markedly amœboid (Fig. 7) and strongly phagocytic. By phagocytic we mean that they have the power of ingesting foreign bodies, including bacteria.

The **eosinophil** or **oxyphile corpuscles** (Plate IV, Fig. 5) possess granules which stain with acid stains. Eosin is the stain usually employed. The granules are very coarse and

PLATE IV

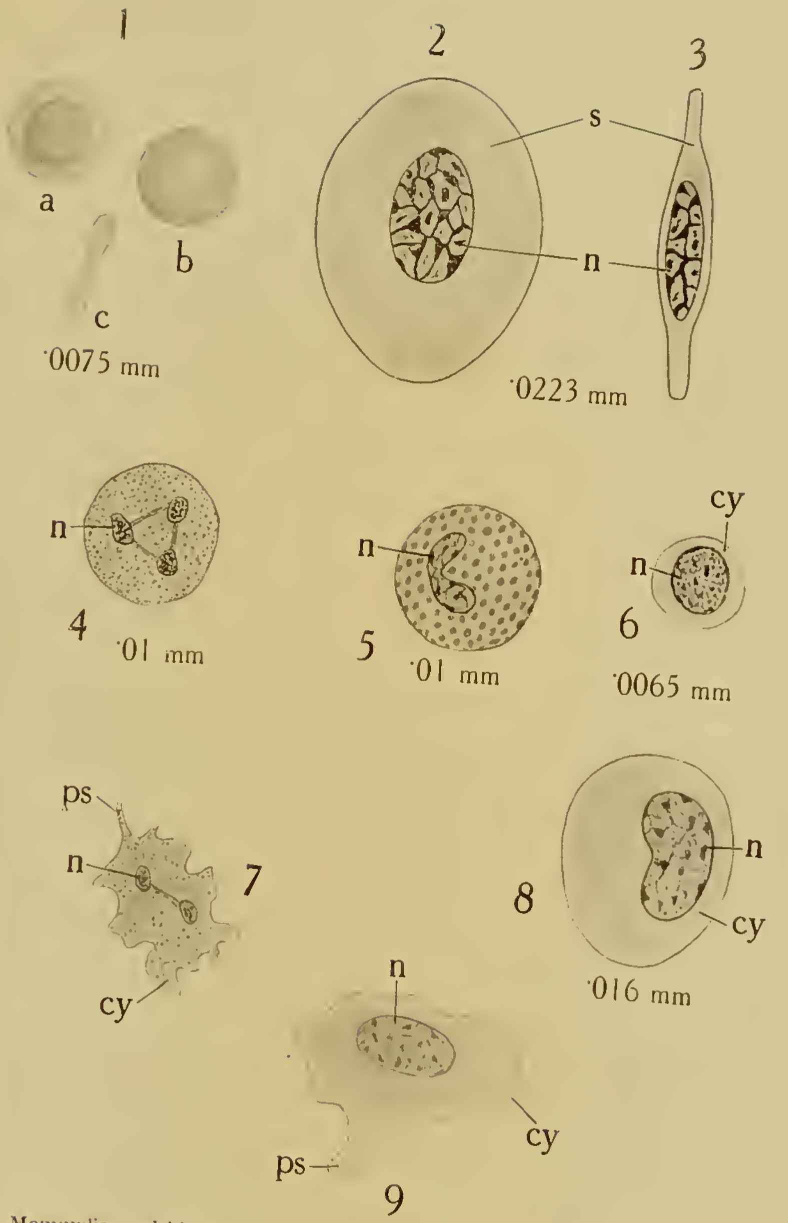

Fig. 1. Mammalian red blood corpuscles. **a** and **b**, seen from surface view in different focus; **c**, seen edgewise. Fig. 2. Red corpuscle of frog seen in surface view. Fig. 3. The same seen edgewise. Figs. 4–9. Different forms of colourless corpuscles. Fig. 4. Polynuclear corpuscle in a condition of rest. Fig. 5. Eosinophil (oxyphile) corpuscle. Fig. 6. Lymphocyte corpuscle. Fig. 7. Polynuclear corpuscle in active amœboid phase. Fig. 8. Macrocyte (hyaline) corpuscle in a condition of rest. Fig. 9. The same seen in a condition of amœboid activity. **cy**=cytoplasm. **n**=nucleus. **ps**=pseudopodia. **s**=stroma. The decimal figures indicate the diameter of the respective corpuscles.

are protein in nature. The corpuscles are about the same size as the polynuclear corpuscles. Their nucleus is usually bilobed. They constitute about 1 per cent. of the colourless corpuscles, though their number appears liable to some degree of fluctuation, and at times they may constitute as many as 10 per cent. of the whole. They are amœboid to a slight extent only.

The **basophil corpuscles** are very rare, being less than 0·5 per cent. of the total leucocytes. They differ markedly in their chemical nature, as indicated by the special way they react towards stains. Their granules are irregular in distribution and unequal in size, and stain intensely with basic stains.

The **macrocytes** or **hyaline corpuscles** (Plate IV, Figs. 8 and 9) are the largest in mammalian blood. They are more than twice the size of the red corpuscle. They are characterized by their clear or hyaline protoplasm (cy), which is quite free of granules. The protoplasm stains weakly with basic stains; or, as we express it, it is weakly basophile. The nucleus (n) is single, large, of variable shape—round, oval or kidney-shaped—and excentric in position. They are highly phagocytic and amœboid, throwing out long pseudopodia (Fig. 9, ps). They constitute rather more than 1 per cent. of the leucocytes.

The lymphocytes (Plate IV, Fig. 6) are the smallest of the leucocytes; they are even smaller than the red corpuscles. Their chief feature, apart from their small size, is the small amount of cytoplasm (cy) and the relatively large size of the nucleus (n). The nucleus frequently stains more uniformly than other varieties. The number present appears liable to fluctuation; on an average they represent about 23 per cent. of the leucocytes, though there may be as few as 15 per cent. and as many as 30 per cent. They appear to be more numerous in infancy than in adult life. The reticular structure of the scanty cytoplasm is brought out well by basic stains and especially by methylene blue.

The size both of the lymphocytes and of the macrocytes appears subject to variation, in the sense that many intermediate sizes are present. This and other features has led to the belief that the lymphocyte represents the early stage of a macrocyte. Both are uninucleate, and in both the cytoplasm is clear and basophile in reaction.

EPITHELIUM

An epithelium is a membranous tissue which covers any internal or external surface of the body. Epithelia are for the most part derived from the outer and inner germinal layers—the epiblast and hypoblast—of the embryo. The only exceptions are the cœlomic epithelia and those lining the cavity of the heart and the blood-vessels, which in most cases are derived from the mesoblast or middle germinal layer.[1]

The epithelial tissues are the earliest formed during embryological development. Compared with other tissues they are relatively little modified, especially certain varieties of them. They are almost wholly cellular in constitution and but little else than cells take part in their formation. They are in this respect markedly contrasted to the connective tissues, the bulk of which is not cellular, but is composed of a more or less structurally modified base or matrix. This matrix is sometimes spoken of as intercellular or extracellular substance, and it is present in various conditions, in most of the elementary tissues. In epithelia it is represented in a minimal quantity as a sort of cement just sufficient to hold the cells together. The cement substance is a secretion of the cells themselves and differs in chemical constitution and reactions to the cell protoplasm. There is some reason to believe that the cement substance is composed of very minute granules, called the **desmochondria granules.** In certain cases the existence of these granules as a constituent of the cement can be demonstrated (Plate V, Fig. 6, tr). They are best seen in "prickle cells" and in those of assimilating epithelia. In the "prickle cells" of mammalian skin the granules are scattered over the surface of the cells, giving them a prickly appearance when seen in section. But in the assimilating tissues (Fig. 6, tr) they are localized along certain tracks, between the cells somewhere near their surfaces, and form bars, called **terminal bars**. These bars invest the cells and consequently form a meshwork, which in surface views will be seen as a honeycombed net. It is probable that the bars and the cement substances generally are impervious to liquids and gases, and consequently it is the cells alone which determine what shall or shall not pass through the epithelium.

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[1] In the chick it seems quite clear that the circulatory epithelium is derived from the hypoblast.

Since the epithelia clothe the surfaces of all organs and of the body generally, they fulfil very diverse functions. They serve as it were as a sort of barrier standing between the environment on the one side and the organism on the other. All that enters the individual from without or is cast outwards from it, must necessarily pass through these epithelia. This is true of stimuli or impulses as well as of material substances. Hence we find epithelia performing many functions. The diversity of function is greater than that of structure. The same type of epithelium (cubical) may line conducting ducts of glands and secrete the limy shells of snails. It is an important fact which should be clearly appreciated, that the ultra-microscopic or molecular structure which determines the physiological nature of a cell, may not always be manifested by visible differences of form. "Things are not what they seem to be" is true of Histology as of other things.

The sense organs of the body are all epithelial in nature and origin. They are really modified patches of ectodermic epithelium. All the glands are but involuted or evoluted foldings or tubules of epithelia. The secretory alveoli of the pancreas and the salivary glands, the gastric glands of the stomach, and the secretory cells of the liver, are derived from the hypoblastic (endodermic) epithelium. Similarly the sweat glands of the skin and the oil glands of the hair follicles are derivatives of the epiblast or ectoderm. The renal tubules of the frog and dog-fish are also epithelial in origin and derived from tubular outfoldings of the mesodermic cœlomic epithelium.

The epithelial lining of glands is either secretory or excretory in nature. Secretory cells are concerned in forming various ferments, mucins, fats or oils, pigments, gases, calcium carbonate, and colloidal poisons of extreme virulency. Excretory cells are engaged in extracting preformed materials from the blood and discharging them unaltered, or in picking out the constituents of the excretory substance and combining them before discharge. Many epithelial cells are modified to receive stimuli from the environment and to pass them on to the central nervous system, through the connecting agency of the nerves. Some are modified in order to produce currents of motion in the channels which they line (Plate V, Figs. 1, 2, 4 and 5). While yet others are modified so as to form a protective and supporting epithelium ; such a cell we see figured in Plate V, Fig. 4, which represents one of the cells of the covering ectoderm of a flat-worm. The vertical filaments traversing the cells tend to give it support and to more effectually protect the inner tissues of the worm. Other epithelia merely serve to line a cavity and render it smooth and moist.

Epithelia may be classified in various ways ; either based upon their embryological origin, their physiological nature, or their structural features. Here, we shall adopt the latter basis and classify them according to the form of their cells. Upon such a basis we may recognize the following types of epithelia : **Squamous, Cubical, Columnar,** and **Ciliated.** These varieties are composed of a single row or layer of cells only. In most such epithelia, the cells rest upon a structureless basement membrane, which is formed as a basal extension of the cement substance (Plate V, Fig. 6). But in a great many of the Invertebrata a basal membrane is not present. An epithelium composed of a single layer of cells may be termed a **Simple Epithelium.** But there are some which consist of several layers and are called **Multiple** or **Stratified Epithelia.** Such an epithelium is seen in the Vertebrate epidermis or ectoderm (Fig. 8), and in that of a few Invertebrata. A stratified epithelium is derived during embryological development from a simple one, partly by mitotic and partly by amitotic division of the cells.

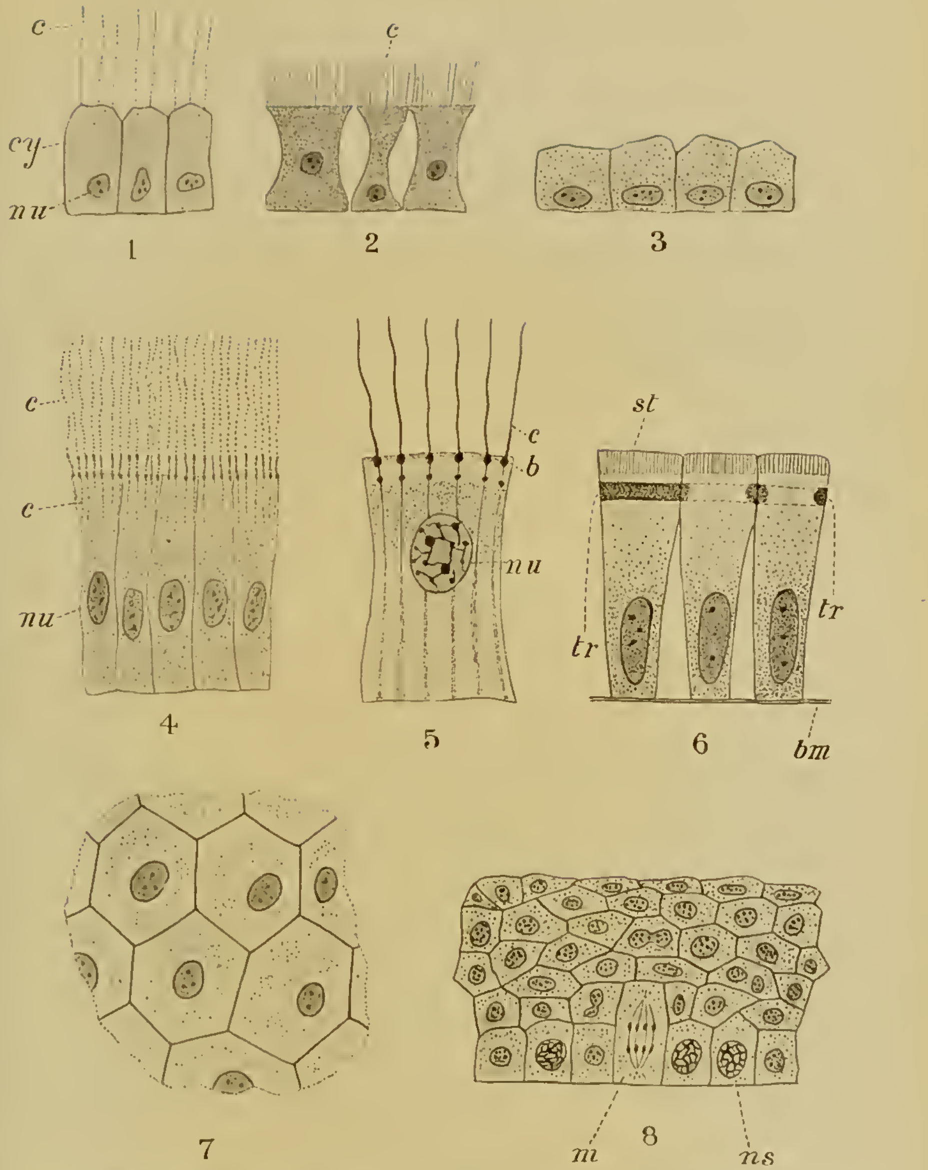


Fig. 1. Columnar ciliated epithelium from stomach of *Gasterostomum gracilescens* (a parasitic flatworm). Fig. 2. Columnar ciliated epithelium from mouth of *Heterochærus* (a free-living flatworm). Fig. 3. Cubical epithelium from the shell epithelium of a snail. Fig. 4. Columnar ciliated epithelium from ectoderm of a flatworm. Fig. 5. Columnar ciliated epithelium from the osphradium of *Sycotypus* (a gastropod). Fig. 6. Columnar epithelium with striated free border and terminal bars composed of desmochondria granules. Fig. 7. Squamous epithelium from human buccal cavity. Fig. 8. Stratified epithelium from umbilical cord. Some of the cells are dividing amitotically and others mitotically. **b**, bead-like enlargement of cilia in cytoplasm of the cell; **b.m**, basement membrane; **c**, cilia; **cy**, cytoplasm; **m**, cell dividing mitotically; **n.s**, nucleus in nuclear skein stage; **nu**, nucleus; **st**, striated free border; **tr**, terminal bar (closing plate) of desmochondria granules.

(A) Simple Epithelia

(1) SQUAMOUS EPITHELIUM

Squamous epithelium lines the buccal cavity of mammals. A variety of it called **tessellated epithelium** lines the body cavity of some animals and the cavities of the heart and blood-vessels. It apparently serves merely to render the cavities which it lines smooth and moist, but it is not improbable that it fulfils important secretory or excretory functions. In a great many organisms an excretory function for the cœlomic epithelium has been experimentally demonstrated.

Squamous epithelium (Fig. 7) is characterized by the thinness or scale-like nature of its cells. It is almost all surface without thickness. In ordinary cases its cells, as seen in surface view, are polygonal or hexagonal in form. But in the tessellated variety the cells have a wavy or sinuous outline so as to appear to be dove-tailed into each other.

(2) CUBICAL EPITHELIUM

A cubical epithelium is composed of cells which are approximately cubical in form; that is, they are about the same length in width, height, and thickness (Fig. 3). Seen in surface view, these cells are polygonal or hexagonal in form. Cubical epithelium occurs in various positions, but chiefly lining the merely conducting, as distinguished from the secretory portions of the ducts of glands. It may, however, occur as an excretory or secretory epithelium, as in the renal tubules of the frog and the shell-forming epithelium of some snails, respectively.

(3) COLUMNAR EPITHELIUM

Columnar epithelium is probably one of the most widely occurring types. Nearly all assimilatory, secretory, and excretory epithelia belong to this type. It is composed of elongate five- or six-sided prismatic-form cells (Figs. 1, 2, 4, 5 and 6). In longitudinal section, they are, of course, only seen as long column-like cells. The ectoderm of *Hydra* and the Earthworm, the epithelium of the alimentary canal and of some of its related glands, and the epithelium lining the trachea and bronchial tubes and the gills of oysters and mussels, are of this type. In some columnar epithelium, the adjacent cells are all in contact with each other along their whole lengths, but in other instances (Figs. 2 and 6), this contact only occurs near the free surface, and spaces are left between the cells towards their basal or attached ends. It is in the columnar epithelium that the terminal bars (*supra*, p. 279) already described may be most readily seen.

The columnar epithelium which lines the intestinal tract of most Vertebrates is characterized by having the free border of its cells vertically striated (Fig. 6). This is called the **striated free border.** In the secretory epithelium of the salivary and pancreatic glands, and in the convoluted tubules of the mammalian kidney, this striation is more extensive and passes throughout the length of the cell.

(4) Ciliated Epithelium

Any type of epithelium may be ciliated. The characteristic feature of a ciliated epithelium is the presence of one or more extremely fine and spontaneously moving protoplasmic filaments extending beyond the free-surface of the cell (Figs. 1, 2, 4 and 5). Apparently cilia fall into two classes. In the one, they are simply prolongations of the surface protoplasm of the cell (Figs. 1 and 2). In the other, they are specialized filaments arising within the cell substance (cytoplasm), and projecting beyond the free border of the cell into the cavity which the epithelium lines (Figs. 4 and 5). In some cases they show a decidedly granular structure in some parts, or throughout their length, and they may in other cases, in addition, show bead-like enlargements just below the free surface of the cell (Figs. 4 and 5). In some instances the cilia arise just within the free-border (Fig. 4), but in other cases they may converge together within the cytoplasm and form a conical bundle which passes deep into the cell. In the cell shown in Fig. 5, the cilia pass throughout the length of the cell in parallel fibres, and here it is probable that the cell part of the cilia serves the purpose of a kind of "stays," giving support to the cell and rendering it more rigid than it would otherwise be.

Ciliated epithelium occurs wherever a constant motion along a chamber or channel is necessary, either to carry off mucus or foreign extraneous particles, or to carry excretory matters to the surface. It is found in the trachea and bronchial tubes of mammals, setting up an outward current; in the buccal cavity of the frog, causing an inward current; in the oviducts of the frog and mammals, and in the pronephric and mesonephric tubules of many Vertebrates, producing an outward current. It also occurs in the central canal of the spinal cord of Vertebrates before birth, but disappears afterwards.

(B) **Stratified Epithelium**

A stratified epithelium is represented in Fig. 8. Its essential feature is its multilayered condition. Its various layers arise from a primarily single layer by mitotic division of its cells. The daughter cells which are thus bedded off may then proceed to divide further, but usually by amitotic division.

A stratified epithelium covers a surface where, owing to its relation to the environment, or to the necessity of a plentiful discharge of some secretory substance, constant destruction of the surface or deeper epithelial cells is occurring. The ectoderm of mammals, the scales of reptiles, and of the legs of birds, are instances of the former kind, while the epithelium which covers the surface of the conjunctiva in the alligator, and that which lines the oil glands of a chicken, of the stink glands of the stink-pot turtle, of the scent gland of the skunk, and the anal glands of the Carnivora, may be cited as examples of the latter.

THE CONNECTIVE TISSUES

The connective tissues may in a sense be described as the passive tissues of the body. The softer forms constitute a kind of packing stuff which supports the active tissues of the body; while the harder or more rigid forms serve as skeletal frameworks. So thoroughly do the connective tissues permeate every part of the organism, that were it possible to remove all other kinds of tissues, such as the epithelial, the muscular and nervous, there would still remain an exact mould of the body, complete in form and manifesting even the minutest microscopic details.

In embryological origin, the connective tissues arise from the mesoblast (mesoderm), and are thus markedly contrasted to the epithelial tissues, which are mainly epiblastic (ectodermic) and hypoblastic (endodermic) in their origin. The two classes of tissues are further contrasted by the relative amount of extracellular substance (cement substance or matrix) which is developed. In the epithelial tissues this material, as we have already seen, is present in only minimal quantity, while it forms the bulk of connective tissues. In other words, the epithelial tissues are practically wholly cellular, while the connective tissues, none the less cellular in origin and in ultimate analysis, are mainly made up of extracellular ground substance.

In embryological tissues, this ground substance or matrix may be of jelly-like consistence, and when it occurs in this form upon the umbilical cord of mammals, for instance, it is known as **Wharton's jelly**. In the earlier stages of their origin, the connective tissues consist of branched stellate cells (Plate VI, Fig. 1, m.c), the fibres or processes of which, in most cases, anastomose with those of adjacent cells. There is thus formed a kind of reticulum or network, the cells lying at the apparent nodes of the net. Between these cells, and filling up the mesh of the network, there is deposited, as a secretion of the cells, a semi-fluid or jelly-like substance, having a muco-albuminous chemical composition. Within this slimy ground substance (**intercellular** or **extracellular substance** or **matrix** as it is technically termed) there are deposited later either threads or fibres of different kinds (Figs. 2, 3 and 4), or else the substance becomes chemically and physically altered to produce, not a semi-fluid ground substance, but a more rigid matrix. The connective tissues which thus develop a more or less completely or partially fibrous matrix, become the tensile tissues and serve to bind or connect other tissues together. These varieties are characterized by great pliability combined with great strength. On the other hand, the varieties in which the ground substance becomes either wholly or partially of a rigid nature, serve the function of support and protect the organisms from the consequences of impact, bending, shearing, or wearing. They become the skeletal tissues.

The above varieties of connective tissues possess an extra cellular secretion or ground substance. But there is one form of connective tissue in which the cell secretion is not secreted to the outside of the cells, but remains within them. In other words, the secretion remains in an intracellular position. **Adipose** or **fatty tissue** is a variety of this kind. It subserves several purposes, but the chief one is probably that of acting as a reservoir of reserve material which may be utilized as a food when the organism is deprived of the ordinary source. Subcutaneous fat, the fat bodies in insects and insect larvæ, and those that are found in various positions in reptiles and attached to the gonads in amphibia, may be mentioned as examples.

The connective tissues may, for elementary purposes, be classified as follows:—

Tensile connective tissues
- (1) *Areolar tissue.*
- (2) *White fibrous tissue.*
- (3) *Yellow fibrous or elastic tissue.*

Supporting connective tissues
- (4) *Cartilage*
  - *Hyaline.*
  - *Fibrous.*
- (5) *Bone*

(6) *Adipose tissue.*

The characters and distribution of each of these may next be studied in the order given.

Areolar Tissue

Areolar tissue occurs as a subcutaneous tissue which binds the skin to the body wall. It also occurs as a packing and binding substance between the muscles.

Its ground substance consists partly of a homogeneous, transparent, soft material, chemically composed mainly of mucin, and partly of two kinds of fibres (Fig. 4, w.f and e.f). Like the cement substance of the epithelial tissues, the clear part of the ground substance readily reduces weak solutions of silver nitrate, and thereby becomes stained brown. The two kinds of fibres present may be readily distinguished. The white fibres (w.f) are individually wavy and unbranched, and are bound together into larger or smaller bundles, which traverse the tissue in all directions in a very sinuous fashion. The yellow or elastic fibres (e.f) run not in bundles, but singly, and are straight and branched. The former fibres are readily affected by the action of weak acetic acid (1 per cent.), and become swollen and transparent, so as to disappear from view. The latter fibres are unaffected by acetic acid.

The cellular contents of areolar tissue are various. For general purposes they may be collectively designated as **connective tissue corpuscles** or **cells.** Four chief kinds occur, *i.e.*, **Lamellar** (l.c), **Clasmatocytes** (p.c), **Plasma** and **Granular** or "**Mast**" cells (g.c). The lamellar cells are flattened and branched. The clasmatocytes vary greatly in size and shape, they are only rarely flattened, and their chief characteristic is the extensive vacuolation of their protoplasm, which is sometimes granular. The granular or "mast" cells are usually rounded or ovoidal in shape, and their cell protoplasm is laden with granules of an albuminous nature, which stain deeply with basic aniline dyes. The plasma cells are rounded or only slightly branched ; they have a small rounded nucleus and the cytoplasm is granular. These granules stain less intensely with basic stains than those of the "mast" cells.

White Fibrous Tissue

Wherever great strength combined with perfect flexibility is required, white fibrous tissue will be found. It thus forms the material of tendons, ligaments, and fibrous membranes. Some tendons and ligaments contain in addition a few elastic fibres, while certain ligaments—the ligamentum nuchæ and the ligamenta sub-flava—are practically wholly composed of the yellow or elastic fibres.

In **White Fibrous Tissue** (Plate VI, Fig. 2, w.f), the matrix or ground substance is wholly composed of very fine white fibres bound together into bundles. These may be again bound together to form larger bundles, and these in turn may be combined to form a tendon or a sheet of tissue. The bundles of white fibres are held together by investments and trabeculæ of areolar tissue. A typical white fibrous tissue may be seen in any tendon of a muscle, and for purposes of observation the long tendons in the tail of a rat, mouse, or ox are easily obtained. Each tendon is composed of a number of bundles of white fibres (w.f), running in a longitudinal direction and parallel to each other, with the **connective tissue corpuscles** or **tendon cells** (t.c) lying between them. These cells are flattened, and are more or less elongate in form. They are usually arranged in chains. The cyto-protoplasm of the cells is drawn out into plate-like expansions or "wings," which pass forwards, backwards, and laterally from the cell, and lie, squeezed as it were, between the bundles. Seen in transverse section such cells appear stellate or branched in form, but in surface view (Fig. 2) they are square or oblong in shape, or in some cases oval. The white fibres become transparent under the action of weak acetic acid, and the cells are then more readily seen.

Yellow Fibrous or Elastic Tissue

Where great strength combined with yielding properties, or where an elastic recoil after pressure or contraction is requisite, elastic tissue will be found.

It forms the major part of the great ligament (ligamentum nuchæ) which runs along the neck and supports the head of long-necked mammals such as the ox and horse. It is found also in the walls of arteries and veins either as a network or as a fenestrated (perforated) membrane. It occurs also in the walls of the trachea and bronchi, and it unites the cartilages of the larynx to each other. In these situations it serves to supply the recoil when the muscular contraction of the related muscles has relaxed. It is found occasionally associated with white fibres, as in areolar tissue (Fig. 4), and it forms an essential element in the ground substance of yellow fibrous cartilage.

It usually occurs in the form of a network of fibres (Fig. 3, y.f), which may be very small or very large, as in the ligamentum nuchæ. These fibres are unaffected by acetic acid. They are bound together into somewhat indefinite bundles by trabeculæ of areolar tissue. They lie embedded in a homogeneous base which is transparent, but is readily revealed by treatment with silver nitrate. In this matrix branched connective tissue corpuscles (Fig. 3, c.t.c) are present.

Hyaline Cartilage

In cartilage (Plate VI, Fig. 6, m.a) the extracellular ground substance or matrix consists of a somewhat rigid material called **chondrin** or **chondrogen.** This material is secreted by the **cartilage corpuscles** or **cells.** As they divide and form more cells, the matrix increases in amount. Sometimes the cell divisions are by mitosis and sometimes they are amitotic. The cell divisions appear to occur, in most cases, by alternating and periodic phases of activity and rest.

The active period seems to extend through two cell divisions which follow in quick succession. In this way groups of four cells are produced. Then the division of the cells temporarily ceases and they begin to secrete around themselves new matrix in concentric layers. The four cells are thus slowly carried apart and become single ungrouped cells. After a time they begin to divide again and the same series of events is passed through. Since some cells will have only just divided into two, and others into four, while others will be in a period of rest, it follows that at any given moment all three conditions of the cells may exist and will be seen in a single section. Some cells will be ungrouped, others in groups of two and others in groups of four. This particular grouping can, however, only occur when the second cell division is at a right angle to the first. But in

PLATE VI

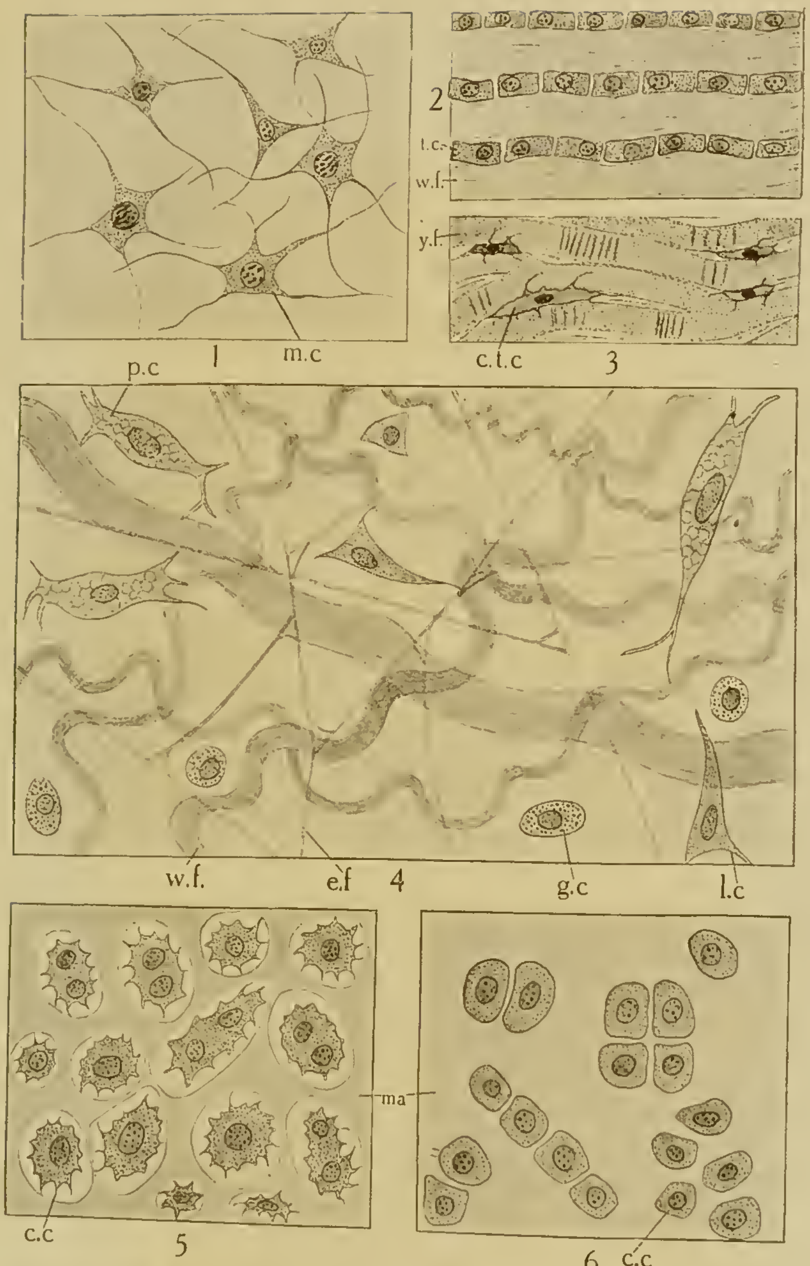


Fig. 1. Mesoblast cells in jelly matrix. Fig. 2. Three bundles of white fibres and three rows of tendon cells (connective tissue corpuscles) from tendon of rat's tail. Fig. 3. A few elastic fibres (yellow fibres) and a few connective tissue corpuscles from a ligament of a cow. Fig. 4. Areolar tissue from subcutaneous tissue of a rabbit. Fig. 5. Young cartilage cells from developing centrum of an embryo mole. Fig. 6. Articular cartilage, untreated with reagents; the capsules of the cartilage cells have merged with the matrix. **c.c**, cartilage cells; **c.t.c**, connective tissue corpuscle; **e.f**, elastic (yellow) fibre; **g.c**, granular ("mast") cell; **l.c**, lamellar cell; **m.c**, embryonic mesoblast cell; **p.c**, clasmatocyte; **t.c**, tendon cell; **w.f**, bundle of white fibres; **y.f**, yellow (elastic) fibre.

some cartilages situated in certain positions, like that which caps the heads of long bones at the joints, and known as **Articular cartilage,** the successive cell divisions are mostly in one plane. This plane varies according to the depth in the cartilage at which the cell divisions are proceeding. In the deeper portions (*i.e.*, near the bone) the planes of division are parallel with the surface of the cartilage, but in the more superficial part they are at right angles to the surface. Between these two zones the planes are at various angles and the grouping into four cells is not then infrequent.

The cartilage cells are usually rounded or oval and unbranched (Fig. 6, c.c). They are so in most Vertebrate cartilages, but in that of Cephalopods (Cuttlefish and Squid), and in some fishes they are markedly branched, and the branches anastomose with each other. This branched condition may be seen even in Vertebrate cartilage upon its extreme free border where it is in contact with its covering of fibrous membrane, the perichondrium, and in the earlier embryonic stages of development. In the later stages of development the branches or processes become retracted and the cells then appear somewhat bluntly angular and irregular in form (Plate VI, Fig. 5). Later still the irregular form of the cells is replaced by the rounded or oval form of fully developed cartilage.

The nuclei of cartilage cells are usually conspicuous. In some cases the cytoplasm stores up a kind of animal starch, called glycogen, and in others fat is similarly stored.

Hyaline cartilage occurs chiefly on the heads of long bones where it forms a sort of cap, and at the sternal ends of ribs. It is also found in the rings of the trachea and the cartilages of the nose. The cartilage found in Cephalopods is also of the hyaline variety and so is that of some cartilaginous fishes, though in this latter case it is often hardened by amorphous deposits of calcium salts. In some Invertebrates and lower Vertebrates the matrix contains mucin instead of chondrogen. It can be recognized by staining yellow with hionin.

Fibrous Cartilage

There are two varieties of fibrous cartilage, namely, **elastic** or **yellow fibro-cartilage** and **white fibro-cartilage.**

In the former the matrix is pervaded with a network of elastic fibres. In the latter the matrix is largely replaced by a large number of wavy white fibres running in one determinate direction. Under the microscope it resembles white fibrous tissue, but may be distinguished from it by the form of its cells, which are cartilage corpuscles and not tendon cells.

White fibro-cartilage is found in the intervertebral discs and is of great strength. The elastic or yellow fibro-cartilage is found in the external ear (but not in the auditory meatus, which is of the hyaline variety), in the epiglottis and certain cartilages of the larynx.

Bone

With regard to its gross structure bone may be classified into two groups, namely, the **compact** and the **cancellated.** The former is apparently solid and heavier, and the latter spongy and lighter. In respect of its origin, bone may be classified as **Cartilage bone** or **Membrane bone.** In the embryos of all Vertebrates, bone is preceded either by hyaline cartilage or by connective tissue membrane. A membrane which is destined to give rise to bone, usually, but not always, invests a cartilage, and it is then known as the **perichondrium.** If bone is developed within this membrane, it is called a **Membrane** or **Perichondrial bone,** but if it arises within the substance of a cartilage, it is then known as **Cartilage** or **Endochondrial bone.**

Bone is developed within cartilage by the operation of two processes. First, the cartilage corpuscles become swollen and ultimately disintegrate. At the same time the matrix becomes calcified. Second, the membrane (the perichondrium) investing the cartilage meanwhile enters the cartilage at the point where dissolution of the cartilage cells first begins. In doing this it carries with it blood-vessels and two sorts of special perichondrial cells, which are later called

osteoblasts and **osteoclasts.** The osteoblasts, when carried into the channels of the disintegrating matrix, deposit bony fibres, and between them granules of calcareous matter. In this way, bone layers are gradually laid down. Meantime, the osteoblasts are themselves necessarily enclosed between the layers which they form. Simultaneously with this bone formation by the osteoblasts, the calcified matrix of the cartilage is being absorbed by the osteoclasts. While the substance of the cartilage is thus being absorbed and replaced by bone, the investing perichondrium is depositing a layer of **periosteal bone** around the central mass formed within the cartilage. This forms the circumferential lamellæ of the finished bone.

Bone which is formed before birth in this way, while possessing a more or less lamellar arrangement of its bony matter, is also largely irregular or reticular in structure. After birth this bone is replaced by another type of bone, in which the bony substance is laid down in a definite series of concentric systems called **Haversian systems.** This later development of new bone is accompanied by a large amount of absorption of the earlier bone by means of the osteoclasts, and the Haversian systems, like the earlier systems, are built up by the osteoblasts. In the fully formed bone these latter are known as **bone cells** or **bone corpuscles.**

Structure and Composition of Bone

If bone be immersed for several weeks in a dilute acid, it will be found to have undergone no change in size or form, but to have lost its hardness and rigidity, and about two-thirds of its weight. It will be quite flexible, and in the case of long bone, it is so much so that it may be twisted and tied into a knot. The substance which remains is its organic matter, and if boiled, it will, like areolar and fibrous tissue, yield gelatine. The action of the acid upon bone removes from it the calcareous salts to the presence of which it owes its hardness. These salts consist chiefly of calcium phosphate, but in addition calcium carbonate and fluoride and magnesium phosphate are also present.

If instead of treatment with acid it be calcined in a slow fire, it still retains as before its size and form, but it loses one third of its weight and also its cohesion. Upon the slightest touch it crumbles to dust. Its organic matter has been oxidized by the process and driven off, leaving only its mineral constituents behind.

From the chemical standpoint, bone thus consists of an organic gelatine-yielding base, impregnated with lime salts.

Minute Structure

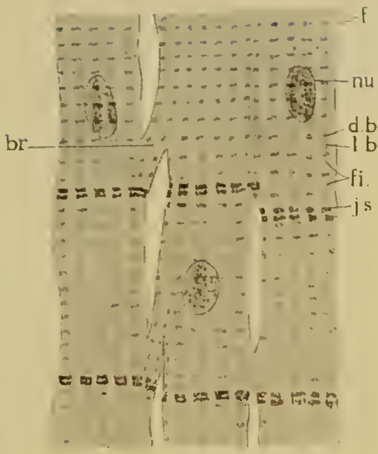
In its ultimate histological analysis—that is, reduced to the simplest terms in which its structure can be expressed—bone consists of a mesh-work of living bone-corpuscles (Plate VII, Figs. 3 and 4, c), with the spaces of the mesh filled up with calcareous salts deposited in an organic base. The bone corpuscles (Text-fig. 63, C) are the homologues of the cells of an epithelium and of the connective tissue corpuscles of fibrous tissues. The hard bony substance is, in bone, the equivalent of the cement substance in epithelium and of the matrix in the other connective tissues. Like other tissues, bone is thus cellular in origin and nature, but as in the fibrous tissues so too in it, the matrix or extra-cellular substance preponderates in amount and constitutes the greater part.

In the bones of the higher Vertebrates, the **bone corpuscles** or **cells** are arranged in definite systems of concentric layers (Plate VII, Fig. 3, c). Between the layers of cells lie the bony lamellæ. In each system these are arranged around a central canal called the **Haversian canal** (H.C). The whole collection of concentric bony lamellæ which lie around any one Haversian canal is called a **Haversian system** (H.S).

Compact bone, like that, for instance, of the long bones of the limbs, is made up of a number of Haversian systems bound together by interstitial and circumferential lamellæ, and arranged around a central tubular medullary or marrow cavity.

The bony lamellæ of the Haversian systems contain minute,

PLATE VII



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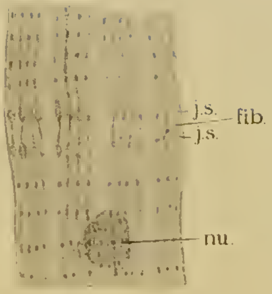

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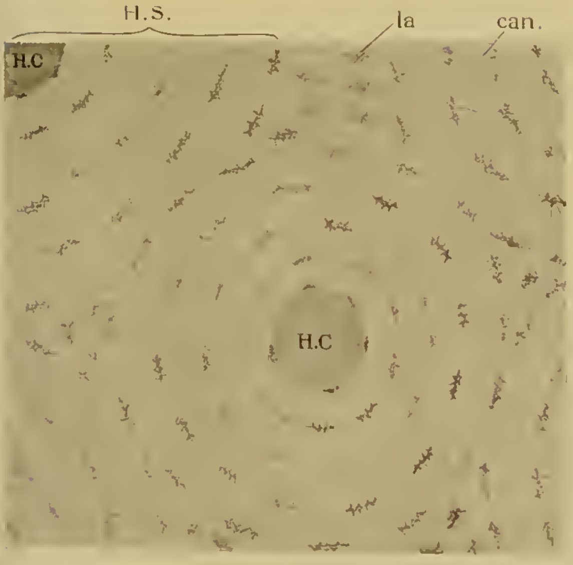

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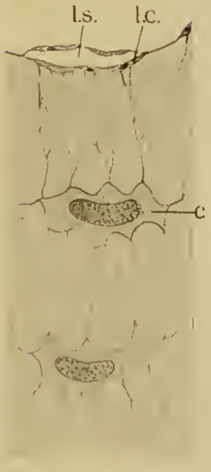

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Fig. 1. A piece of cardiac muscle fibre. Fig. 2. A piece of the same in the region of the junction stripe, highly magnified to show the connecting fibrils (**fib**). Fig. 3. Transverse section of bone. Fig. 4. Piece of same adjacent to a Haversian canal (**H.C**) to show lymph space (**l.s**) and the continuity of the lymph cell (**l.c**) processes with bone cell (**c**) processes. **br**, branch of cardiac muscle fibre; **c**, bone corpuscle = bone cell; **can**, canaliculi; **d.b**, dark band; **f**, muscle fibre = muscle cell; **fi**, muscle fibrils; **fib**, delicate junction fibrils which maintain a continuity between the muscle fibrils of adjacent muscle cells; **H.C**, Haversian canal; **H.S**, part of a Haversian system; **j.s**, junction stripe = intercalated disc; **la**, lacuna; **nu**, nucleus.

irregularly shaped spaces called the lacunæ (la). The lamellæ are also pierced through their thickness by a number of very small, not infrequently branching, canaliculi (can). These open from one series of lacunæ to adjacent ones (Figs. 3 and 4), so that the lacunæ in a Haversian system are thus put in communication with many others. Each lacuna contains a bone corpuscle (Plate VII, Fig. 4, c and Text-fig. 63 C). This is an irregularly shaped cell with many very delicate protoplasmic filaments (C.P) passing out from it. They traverse the canaliculi and join others coming from adjacent bone corpuscles. In this way a network of living bone cells is formed. The nucleus (nu) of a bone cell is relatively large. Each bone corpuscle is closely invested in a special bony sheath forming the wall of the acuna (C.I), which is more resistant to the action of acids han are the calcium salts of the general ground-work.

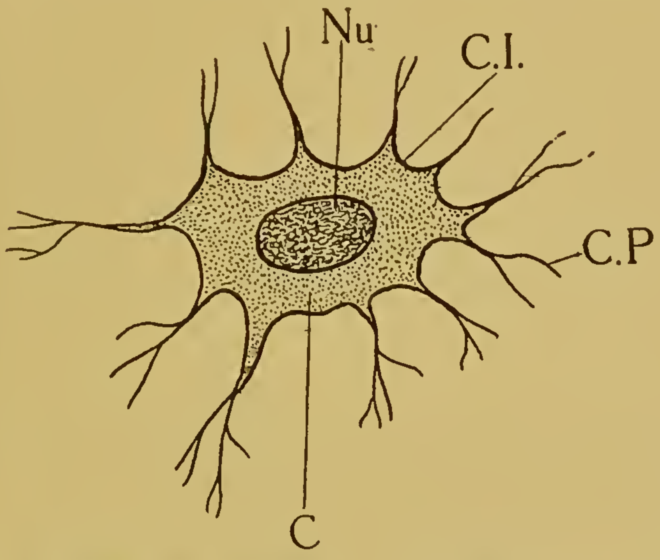


FIG. 63.—Isolated bone corpuscle. **C.** Cytoplasm of bone cell (bone corpuscle). **C.P.** Processes of bone cell. **C.I.** Neumann's layer or special bony sheath of the lacuna, which closely invests each bone corpuscle. Neumann's layer belongs to the matrix and is a specially resistant portion of it, resisting acids after other parts have been dissolved.

The canaliculi of the innermost bony lamella of a Haversian system (Plate VII, Figs. 3 and 4) open into the Haversian canal.

This contains an arterial capillary vessel bringing blood to the canal and a larger venous capillary taking blood away. In addition nerve fibres traverse the canal, and lymphatic vessels (l.s) are also present. All these vessels are embedded in a delicate variety of fibrous tissue containing branching connective tissue cells. From the walls of the lymphatic vessels, certain of their cells (l.c) send branching protoplasmic filaments through the canaliculi of the innermost lamella, and these anastomose with those of some of the bone corpuscles. The Haversian system as a whole is probably partly nourished by the blood plasma which exudes through the walls of the thin capillaries, and which, percolating through the canaliculi and lacunæ, permeates the bone cells. In part also, no doubt, the outer bone cells are nourished by the agency of the innermost ones which are immediately in relation with the contents of the Haversian canal. The bone cells of a Haversian system are really members of a colony, and their nutrition is a common act: nutriment absorbed at one part diffuses indirectly through the whole.

The blood-vessels, lymphatics, nerves, and connective tissues present in the Haversian canals are carried there by ingrowths of the periosteum or membrane which externally invests the bone as a sheath-like covering.

In the long bones of the frog there are no Haversian canal systems. A transverse section of a frog's femur shows it to be built up of a few concentric layers which are arranged around the marrow cavity, not around a Haversian canal. The innermost lamellæ are thinner and present a more refractive appearance than the outer ones. The whole thickness of the bone—that is, the whole series of bony layers—is pierced by nutritive canals passing from the periosteal surface to the marrow cavity. The bone in the course of development is formed by two osteogenetic membranes, one lining the marrow cavity and the other forming the inner layer of the investing periosteum.

The higher Vertebrate bone (rabbit and Man) passes through a stage not dissimilar to that of the frog. The

Haversian canal system is not primary but secondary, and is formed, as we have seen, after birth, by the absorption and rearrangement of the embryonic bone.

Every long bone is composed of a shaft and two terminal portions or epiphyses. All three ossify from a separate and independent centre of ossification, formed by distinct periosteal ingrowths into the primary cartilage rod, in which the bone is to be preformed. The three centres of ossification do not meet, however, until relatively late in development, and between them there lies a core of primary cartilage, in which the cartilage corpuscles are continually dividing and forming new cartilage. It is at these two points, one at each end of the shaft, between it and its two epiphyses, that growth in length chiefly takes place. The bone substance itself can increase after its formation, as is shown by the fact that the bone corpuscles are wider apart in an adult bone than in that of an infant. But such increase, either in length or width, is relatively very little. The increase in diameter of a bone is by the deposition of fresh bony layers by the osteoblasts of the periosteum.

Membrane bone is formed by the deposition in the ground substance, between the fibres of a connective tissue, of a granular deposit of calcium salts. A connective tissue membrane, destined to become bone, contains within it a large number of osteoblasts and blood-vessels. The former deposit the lime salts around the connective tissue fibres, which are called **osteogenetic fibres,** and the tubular bony investments thus formed are known as bone spicules. As these thicken they tend to run together, but leave here and there spaces in which blood-vessels and bone corpuscles (osteoblasts) are lodged.

Adipose Tissue

Adipose or fatty tissues may be regarded as modified forms of fibrous tissue. When they first arise, they have the embryonic characters of any other connective tissue. Their special function is to store up food material as a reserve which the animal can utilize at such times as the ordinary sources of food are not available. But doubtless fat has other functions, and its extremely vascular condition may not only allow the organism to extract nutritive material from the fat, but not improbably it allows of a relatively large amount of oxygen to be temporarily, and under normal conditions, continually stored. In some cases, too, fat may act the part of a "buffer" tissue or as a sort of "packing" or "filling" tissue, filling up what would be otherwise empty cavities between the other mesodermal tissues. Fat being a modified connective tissue, it is, like the others, of mesodermal origin. It occurs in many different situations, but always in relation to the course and distribution of the smaller blood-vessels. It is very vascular, and its constituent cells are largely bound together by, and held within the meshes of, blood capillaries. In addition the fat cells are supported and built up into more or less lobular masses, by connective tissue cells and by fibres of areolar tissue.

Tracing the development of a fat cell, we find at first it is a somewhat granular ordinary connective tissue cell. It appears to have the property of taking up certain materials from the blood fluid in which it is bathed, and depositing them in the form of fatty acid droplets within its substance. As the droplets grow in size and increase in number, they run together and form drops; these in their turn run together and form larger drops; when these become very large they may be called vacuoles of fat. Ultimately only one large vacuole is left, and this is so large as to practically occupy the whole of the cell, except for a thin vesicle-like investment of cell protoplasm which surrounds it. Within this protoplasmic sheath is lodged the nucleus of the fat cell.

Regarded from the morphological standpoint, the fat substance may be regarded as the homologue of the matrix of other connective tissues or of that of the cement substance of the epithelial tissues. But there is this distinction between them. In the epithelial and connective tissues—other than fat—the morphological matrix is deposited by the cells outside themselves; that is, it lies between or among the cells. We may therefore speak of it as an **extra-cellular** or **inter-**

cellular matrix. But in fat, the morphological matrix is deposited within the cells and may be therefore distinguished as **intra-cellular matrix.**

In the Invertebrata fatty bodies are known, and they are morphologically similar to the fatty tissues of Vertebrates. But their food-reserves appear to be more allied to the reserves found in the liver of Vertebrates than to the fatty acids found in Vertebrate fat.

As more or less special features, we may mention the fatty bodies of the Amphibia and Reptilia. In the frog and toad, these fatty bodies—the corpora adiposa—are attached to the anterior end of the testes and ovaries. They represent, indeed, the degenerated anterior half of the genital ridges, out of which the gonads arise. In some lizards, half-moon-shaped masses of fat are found at the anterior border of the pelvis lying between the peritoneum or cœlomic epithelium and the muscular coat of the body-wall, and other masses may be found lying along the course of the postcaval vein.

In the Amphibia the fatty bodies may in some cases serve as a reserve of food during the hibernation of Winter, which occurs in Temperate Zones. But not improbably they may also serve as sources of nutriment for the developing gonads of which they are morphologically a part.

In the Insecta, fat bodies or masses are found in both the larva and the imago.

The Muscular Tissues

The muscular tissues in the Vertebrata are usually arranged under three classes :—

(1) **Plain, Unstriped**, or **Involuntary fibre.**
(2) **Striped** or **Voluntary fibre.**
(3) **Cardiac fibre.**

But even among the Vertebrata there occur fibres that are not wholly one or the other, but in a sense a combination of the plain and striped. In the Invertebrata quite a large number of organisms possess muscle fibres which, while not wholly plain, are neither entirely striped. The plain or unstriped fibre is the more primitive kind, and the striped fibre in its highest development is a very highly specialized form of tissue.

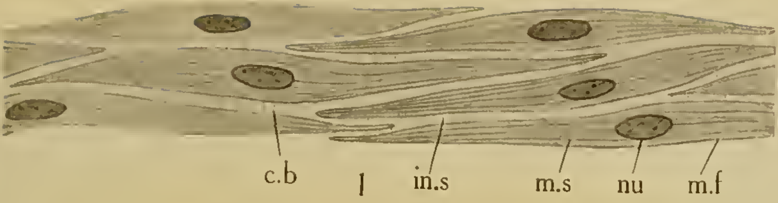
The unstriped variety is usually found in situations where a slow, rhythmical and continuous action is required. The striped variety, on the other hand, occurs where sharp, sudden, and forcible but more or less momentary or sporadic movements are desirable. The difference in function between the two types is well exemplified in the different habits of the oyster and the pecten. Both close their shells by a band of muscular tissue which stretches across from one shell to the other. But though these two animals are closely related, in the oyster the muscle is unstriped, and in the pecten striped. While the oyster is fixed and sedentary, the pecten is active and free-swimming, moving through the water by rapid and forcible alternate opening and closing of the shell.

Plain fibre is sometimes called involuntary, because in Vertebrata it occurs in organs which are not under the control of the will. Such organs constitute the viscera. The heart, which is an exception to the statement, contains a special fibre. Striped fibre is sometimes called voluntary, because it occurs in the skeletal muscles, and these are under the influence of the will.

Unstriped Muscle

Muscular tissue is made up of muscle fibres (Plate VIII, Fig. 1, m.f). In the unstriped variety these fibres are single cells. They are bound together by a kind of cement substance (in.s) into bundles or into flat sheets. The bundles may branch more or less. In some cases the cement substance can be seen to be traversed by very fine transverse fibrils (c.b), which probably represent protoplasmic filaments of the muscle cells. If this be so, then unstriped muscle tissue may be conceived as a protoplasmic network, the whole working in anatomical as well as in physiological unison.

Each muscle fibre or cell consists of an undifferentiated cytoplasm (Plate VIII, Fig. 1) traversed by a number of differentiated fibrils (m.s). These probably endow the cell with



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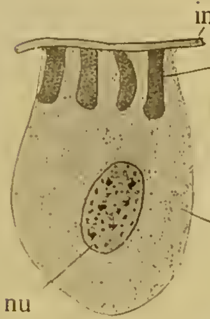

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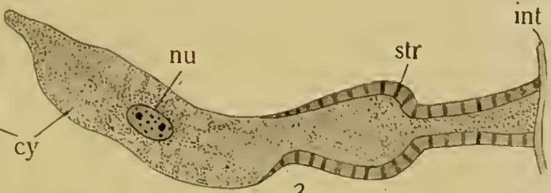

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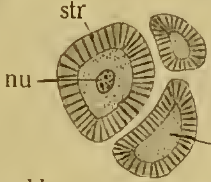

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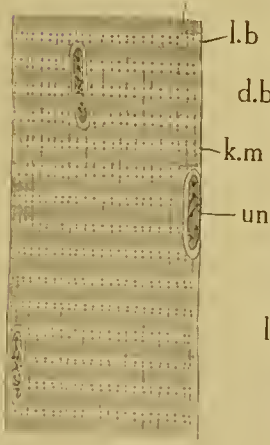

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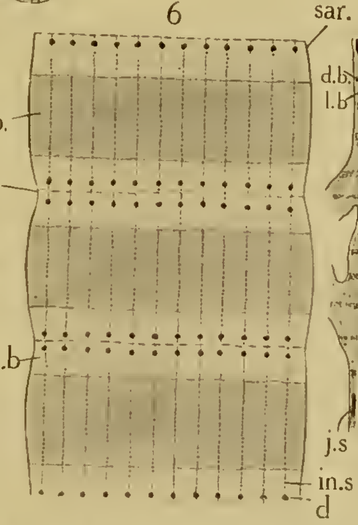

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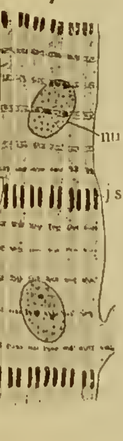

Fig. 1. Unstriped muscle fibre. Fig. 2. Muscle cell from beneath integument of a Nemertean, *Cerebratulus*. Fig. 3. The same from a Threadworm, *Ascaris*. Fig. 4. Transverse section of muscle cells from the Leech (Hirudino). Fig. 5. Striped muscle fibre. Fig. 6. The same from an insect; stained with gold chloride. Fig. 7. A piece of cardiac muscle fibre. **c.b**, protoplasmic connecting bridges between muscle fibres; **cy**, undifferentiated cytoplasm of muscle cell; **d**, row of dots or granules; **d.b**, dark band; **in.s**, intercellular cement substance in Fig. 1. In Fig. 6 **in.s** is the sarcoplasm between the sarcostyles; **int**, integument (ectoderm); **j.s**, junction stripe or intercalated disc; **k.m**, Krause's membrane = Dobie's line; **l.b**, light band; **m.f**, muscle cell = muscle fibre; **m.s**, muscle fibrils = myo-fibrils = myophanic striations; **nu**, nucleus; **sar**, sarcolemma; **str.**, differentiated striped portion of cell protoplasm; **un**, nucleus in bleb of undifferentiated protoplasm.

its contractile properties. They may be called the **muscle fibrils, myo-fibrils,** or **myophanic striations.** Lying in the middle of the fibre is the nucleus (nu), which is always single and generally elongate in form. The muscle fibre of the unstriped variety of muscle possesses no investing sheath or sarcolemma.

In some Invertebrata interesting forms of muscle fibres are seen. In the Nemertean, known as *Cerebratulus* (Plate VIII, Fig. 2), the muscle cells of the body-wall consist for the most part of a granular, undifferentiated protoplasm (cy), in which the nucleus (nu) is lodged. At the outer end of the cell, where it is attached to the ectoderm, the cell contains a few deeply staining but relatively thick muscle fibrils (str). These probably represent the chief, if not the sole, contractile substance of the cell. In the threadworm, *Ascaris* (Plate VIII, Fig. 3), we have a similar type of cell, but the striped portion (str) is greater in extent and forms a sort of cylindrical stalk to the cell. In the Leech (Fig. 4) the fibre is long and spindle-shaped, the core being composed of the undifferentiated protoplasm (cy), while the periphery, or outer zone of the cell, is composed of the striped portion (str). In Plate VIII, Fig. 4, three such fibres are shown cut transversely across.

Striped Muscle

Striped muscle fibre really represents a syncytium of cells. That is, it is a fusion of the protoplasm of a number of cells, the nuclei remaining free. The fibres are long and cylindrical in form. They are often an inch or more in length and $\frac{1}{500}$th of an inch in diameter. Striped muscle fibre differs from the unstriped kind in the presence of an exceedingly thin elastic film called the **sarcolemma** (Plate VIII, Fig. 6, sar). It is difficult of demonstration owing to its tenuity, but it may be sometimes seen at the broken ends of fibres, or where the muscle substance has been ruptured.

It cannot be said that our knowledge of the structure of striped muscle is yet completed. Many things which can be seen are difficult of explanation, and the interpretation of them is therefore very doubtful.

But any striped muscle fibre will show clearly enough under ordinary conditions that the muscle substance enclosed within the sarcolemma is differentiated into alternate transversely arranged **light** and **dark bands** (Figs. 5 and 6, l.b and d.b). This differentiation is probably both chemical and physical in origin, and the optical appearances are but the manifestation of the physical differences of the two kinds of bands. The two bands stain differently, indicating a difference in chemical constitution ; the clear or light band does not readily stain, while the dark band stains deeply. The difference in the staining properties of the two bands is well seen in insect muscle which has been stained by gold chloride. The physical difference of the two bands is demonstrated by their behaviour in polarized light between two crossed Nicol's prisms. Under these conditions the light band shows dark like the dark optical field, while the dark band shows light. This optical difference is expressed by saying that the light band is isotropic and the dark band is anisotropic.

The muscle substance of striped fibre is therefore, in a sense, divided into alternating discs which are chemically and physically different. The chemical difference is shown by differences in staining and the physical by the different optical behaviour of the two bands in the darkened optical field of crossed Nicol's prisms.

Some other features in the structure of a striped muscle fibre are better seen in the muscles of arthropods, such as lobsters and insects. In them the light band can be seen to be traversed by a transverse, exceedingly fine line called **Dobie's line,** or **Krause's membrane** (Figs. 5 and 6, k.m). Whether it is a real membrane or merely an optical appearance produced by the interference of light still remains a disputed point. On either side of Krause's membrane there is a row of dots or granules (d). These are connected with a number of longitudinal striations (in.s) and appear to be located along their length. At certain phases of contraction there can be seen passing across the middle of the dark band a light line, known as **Hensen's line.** It is probably indicative of the last phase of contraction of the fibre.

The numerous nuclei (nu) of the muscle fibre in the Mammal lie beneath the sarcolemma, invested by a thin film of undifferentiated protoplasm. In the frog they lie embedded in the muscle substance. In the insect fibre they lie along the central core, which is traversed by a string of undifferentiated protoplasm.

When muscle fibre is treated with certain reagents or is thoroughly teased along its length it can be split up into fibrils. Each of these is then seen to correspond to one of the strings or columns of muscle substance which lie between the longitudinal striæ. Each fibril is called a **sarcostyle,** and observations made upon transverse sections of a fibre when compared with a longitudinal view lead us to believe that a muscle fibre is really made up of a number of sarcostyles embedded in an undifferentiated protoplasm which is called the **sarcoplasm.** Since the sarcostyles are set closely together it follows that the sarcoplasm between them must be exceedingly thin. It is thus clear that, seen in longitudinal view, the sarcoplasm will be seen as the series of longitudinal striæ (in.s). The two rows of dots seen in the light band are interpreted as being nodal enlargements of the sarcoplasm. The muscle fibre itself is formed by enclosing the sarcoplasm and sarcostyles in a common sheath with the sarcolemma.

In the muscle fibres of some animals the sarcoplasm is very abundant, and here and there within the fibre is widened out into thick strings in which the nuclei lie. It is not improbable that the sarcoplasm carries on the general nutritive functions of the fibre, and is the seat of the metabolic processes involving assimilation, respiration, and excretion. This leaves the protoplasm of the sarcostyles freer for the performance of those particular chemical changes upon which the specialized function of contractility appears to depend. We find, as we shall see later, that a very similar condition appears to exist in nerve cells. In them there is an undifferentiated cell-protoplasm—the cytoplasm—possibly carrying on the general functions of nutrition, and, in addition, there are specialized tracts or fibrils which are probably chiefly concerned in the transmission of nerve impulses.

Cardiac Fibre

In some respects cardiac muscle fibre (Plate VII, Figs. 1 and 2, and Plate VIII, Fig. 7) is intermediate in its structural features between the unstriped and the striped varieties. It resembles unstriped fibre in the absence of a sarcolemma and in the possible distinctness or independence of the fibres from each other. But it resembles striped fibre in the presence of alternate dark and light bands. It differs from both in that the transverse markings (light and dark bands) are not so distinct as in striped fibre, and in that the cardiac fibres branch and anastomose with adjacent fibres. Moreover, the nuclei do not lie immediately underneath the sarcolemma, but in the muscle substance, with a tendency to shift towards the central core of the fibre.

This account of cardiac muscle fibre will probably require some modification in the future. There are observations which seem to indicate (Plate VII, Fig. 2, fib) that the independence of the individual heart fibres, in the sense that each is a single cell sharply demarcated from its fellows and joined by cement substance, is a wrong conception of the nature of the case. There are several facts which give support to this doubt, but there are also others which weigh against it. It can be shown, for instance, by appropriate methods and sufficiently high powers, that the fibrils (fi) of the fibres (f) are continuous (fib) from one cell to another (Plate VII, Figs. 1 and 2). But at the line of junction (J.S) of the fibrils of one cell with those of the adjacent cells, the fibrils are modified and appear to be composed of a denser and chemically different substance (J.S). This denser portion of the fibril, occurring only at the junction of the muscle cells, forms, in the aggregate of fibrils, a sort of disc, which may be called the "intercalated discs" (J.S). It is possible that these discs are not contractile. The muscle fibrils are in some cases, at least, seen to be continuous from cell to cell by very fine connecting fibrils (fib).

With regard to the sarcolemma, there exists a very fine connective tissue investment with narrow flat nuclei, which may possibly represent a form of sarcolemma. If this is so, then the statement that cardiac fibre has no sarcolemma will require some qualification.

The Nervous Tissues

Every organism must be capable of adapting itself to each change in its environment, or ultimately perish. At every moment of its life various external stimuli are incident upon it, calling forth adequate and appropriate responses. These stimuli may be chemical, physical, or mechanical in nature. Were the organism incapable of feeling these stimuli it could not respond to them, and would therefore be incapable of adapting itself to ever-changing conditions. Such passivity with regard to the environment would result sooner or later in eventual destruction.

The organs of sensation by which external stimuli are felt or appreciated and those which transmit, receive, and generate stimuli, belong to the nervous tissues. The organs which receive the external impulses are the various sensory nerve endings, such as the tactile bodies in the skin, the specialized cells in the taste organs of the tongue, and those in the olfactory and auditory epithelium and the rods and cones of the retina. Stimuli received by them are conveyed along nerves to nerve cells with which these are individually connected. Within the nerve cell some change apparently occurs, and another stimulus, or the same stimulus in a modified condition, is passed along another nerve fibre to the motor end organ. This is lodged about the middle of a muscle fibre. When it receives the stimulus from the nerve cell it in some way generates a muscular contraction in the muscle fibre.

We thus have as an anatomical entity or unit a nerve cell (Text-fig. 64, 1), receiving on the one side a nerve process carrying stimuli to the nerve cell, and on the other giving off a nerve process along which stimuli pass away from the nerve cell. The ingoing or afferent nerve fibre commences in a sensory nerve-ending of some sort (P), and the outgoing or efferent nerve fibre ends in the motor end plate. The whole constitutes a physiologically and anatomically complete nerve apparatus for the reception, perception, modification, and discharge of stimuli. It is a unit piece of mechanism, and has been called a "**neurone.**"

The "neurone-theory" postulates that the nervous system is an aggregate of a large number of neurones, each of which is *anatomically* independent of the others. The simplest neurone path which we can conceive is that described above,

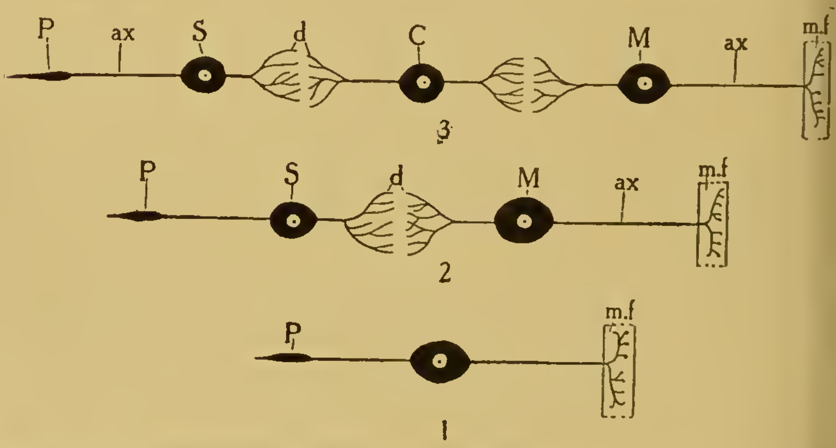

Fig. 64.—The neurone theory of the sensory and motor reflex nervous mechanism diagrammatically represented. 1. The simplest form of mechanism, consisting of one neurone. 2. A more complex form, consisting of one "sensory" neurone and one "motor." 3. A more complex system still in which the "sensory" and "motor" neurones are connected by a third or "communicating" neurone. **ax** = Axon (neuraxon). **d.** Dendrons. **m.f.** Muscle fibre in which the motor end-plates are lodged. **C.** Nerve cell of "communicating" neurone. **M.** Nerve cell of "motor" neurone. **P.** The sensory or perceptory nerve ending in some sensory epithelium. **S.** The nerve cell of "sensory" neuron.

where only one neurone takes part in the cycle of nerve action.

A more complex neurone cycle is where two neurones are concerned (Text-fig. 64, 2), one being connected with the sensory (S) and the other with the motor phase (M) of the nerve path.

A yet more complex condition is where three neurones are present (Text-fig. 64, 3). One of these is the sensory or perceptory neurone (S), the second is a sort of bridge (C) serving as a communication with the first and third or motor neurone (M). It is possible the communicating neurone between the sensory and motor neurones may in some way modify, weaken, hasten, retard, or even inhibit, the impulses passing along the nerve path.

The anatomical independence of the neurones depends upon the apparent fact that the various nerve processes (d) of one neuron are not continuous with those of another. There are minute intervals between them. Physiologically, of course, impulses travelling from one neurone to the other must be able to traverse these intervals, or otherwise the whole neurone arrangement is meaningless. But there is reason to believe that this anatomical independence is not as complete as was first thought, for in some worms a direct anatomical or organic connexion between the fibrils of different neurones can, by appropriate methods, be demonstrated.

The nature of the nerve impulse which passes through the neurone or series of neurones, from the sensory end organ to the motor end organ, is not yet clearly understood. Its time reaction seems to show that it is not wholly or specifically electrical; it may be in the nature of chemical changes moving along the nerve path, producing new reactions at definite points, but this we cannot at present definitely assert. In the nerve cell itself the nerve stimulus may possibly pass through or be regenerated in the cytoplasm of the cell. But in some nerve cells (Plate IX, Figs. 1 and 2) special methods of preparation have shown that definite fibrillar anastomosing paths (r) exist within the cytoplasm, and it is highly probable that it is along these specialized paths that the nerve impulses travel. It is not improbable too that some of these cell fibrils are efferent paths and others are afferent.

Classification of Nerve Cells

Nerve cells may be morphologically classified according to their form. Like their size, form is manifested throughout a wide range. In form, nerve cells may be spherical, spindle-shaped (Text-fig. 65, 1), pear-shaped (2 and 3), irregularly star-shaped or stellate (4). Their form largely depends upon the number of nerve processes arising from them, and the morphological description of the different types of nerve cells turns chiefly upon the relation of the cell to its processes. If but one fibre or process arises from the cell (Text-fig. 65, 2) it is called a **unipolar cell.** Such cells, as a rule, are round. They form the majority of nerve cells, and are chiefly found in the ganglia of the spinal nerves. The process usually divides into two branches not far from the cell-body, one branch travelling inwards to the central nervous system (spinal cord) and the other outwards towards the peripheral sensory end organ. Unipolar cells are also found in some of the ganglia on the root of cranial nerves. Such nerve cells are usually adendric, that is, without dendrons (*infra*, p. 309).

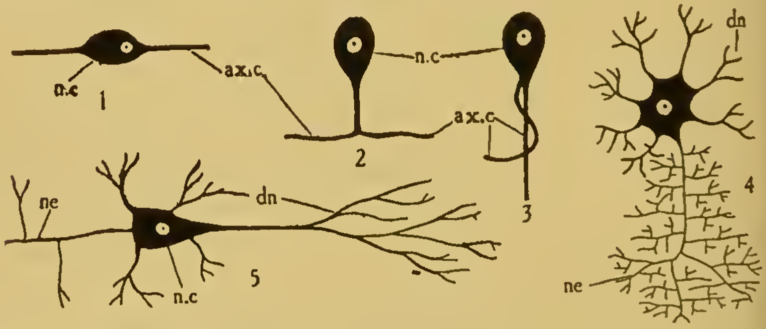

FIG. 65.—Type of nerve cells. 1. Bipolar. 2. Unipolar. 3. Another form of bipolar cell. 4 and 5. Multipolar. **ax.c.** Axis cylinder. **dn.** Dendrons. **ne.** Neuraxons. **n.c.** Nerve cell.

Bipolar cells, (Text-fig. 65, 1) have a fibre coming off from each end of the cell. Such cells are usually spindle-shaped in form. They occur in much the same situations as the unipolar cells. And, indeed, in their early stages of development, most unipolar cells show the bipolar condition; their unipolar condition is an acquirement of later embryological development. A few bipolar cells are pear-shaped (3), and the two fibres come off from the same end of the cell; these at first twist round each other. They are found in the ganglia of the dorsal roots of the spinal nerves of the frog.

The next type is the **multipolar** cell. The form of this may be triangular (5), irregularly star-shaped, or stellate (4).

Three or more processes arise from such a cell. The processes are not all of the same nature (*infra*, p. 309). This type of cell is found in the grey matter of both brain and spinal cord.

With regard to size, some of the nerve cells are among the largest in the body, while others are very small.

Generally speaking, in the Vertebrata, nerve cells occur only in the grey matter of the brain and spinal cord, and in ganglia situated along the course of nerve trunks. In the Invertebrata they are confined to the nerve ganglia, and are not found in the nerve trunks. In the earthworm, ganglia do not occur, except the single pair on the roof of the buccal sac, and in this case the nerve cells are found uniformly distributed along the two nerve chains, but not in the nerves. In lower Invertebrata, such as *Hydra*, nerve trunks or chains are not developed. The nervous system in them is diffuse, and the nerve cells lie just beneath the ectoderm, more or less uniformly distributed.

THE STRUCTURE OF THE NERVE CELL

A nerve cell, with its processes, is among the most highly specialized cells in the body, and highly specialized functions belong to it. But it is still a living cell, and must in some measure also perform those general functions of nutrition which pertain to all cells. There is some reason to believe that these general functions are relegated to the undifferentiated cytoplasm or neuroplasm of the cell (Plate IX, Figs. 1, 2, 3 and 4), while the specialized nervous functions are more particularly related to specialized tracts within the cell and cell processes (dn, ne, r). The cytoplasm of many cells (multipolar cells of grey matter of spinal cord) is traversed by a number of very fine fibrillæ, which pass out into the various processes. In other nerve cells these fibrillæ form a definite network or anastomosis (Plate IX, Figs. 1 and 2), the nerve impulses probably passing in along one set and out along another.

The nucleus (nu) of a nerve cell is characteristic. It is large and rounded. The nuclear membrane is relatively thick. As a rule there is a distinct linin thread, forming a network, and containing numerous chromatin grains.[1] This network, however, is not always present, and then the chromatin is variously arranged. It may be diffused through the nuclear sap as a very fine dust, or it may occur in groups or threads of larger granules, or in large masses. In some diseased, as in some normal cells, the chromatin may manifest various changes.

The nucleolus (nl) is usually large and definitely round. It is very conspicuous, and sometimes more or less vacuolated.

As a rule nerve cells contain only a single nucleus; but there may be two or three nuclei in some cells, as in the sympathetic ganglia of some rodents, and sometimes in the cells of the grey matter of the spinal cord of some fishes.

Besides the fibrils and neuroplasm, the cytoplasm contains a number of very deeply staining, large, angular grains (Plate IX, Figs. 3 and 4, n.g). They appear to be chemically composed of nucleo-protein, and contain organically combined iron. The stain which reveals their presence best is methylene blue. These grains are called by English writers **Nissl's granules,** and by American, **chromophyllic masses** or **tigroid bodies.** They are apparently not homogeneous in nature, but each Nissl granule appears to be composed of a number of aggregated granules. The ultimate granules have been called by some the **neurochondria.**

The Nissl granules play an important part in the economy of nerve cells. This is shown by the reduction in size, disintegration, and change in distribution, which they undergo when the nerve cells are over-fatigued or are subjected to the influences of various poisons, or to the toxins of disease. They possibly serve as food masses for the trophic processes of the nerve cell.

Some nerve cells appear to be without Nissl's granules. It is possible, however, that they may be present in some form not yet revealed by the present methods of staining applied to the cells. Nissl granules, when present in the nerve cell, are also found in some of its processes and are

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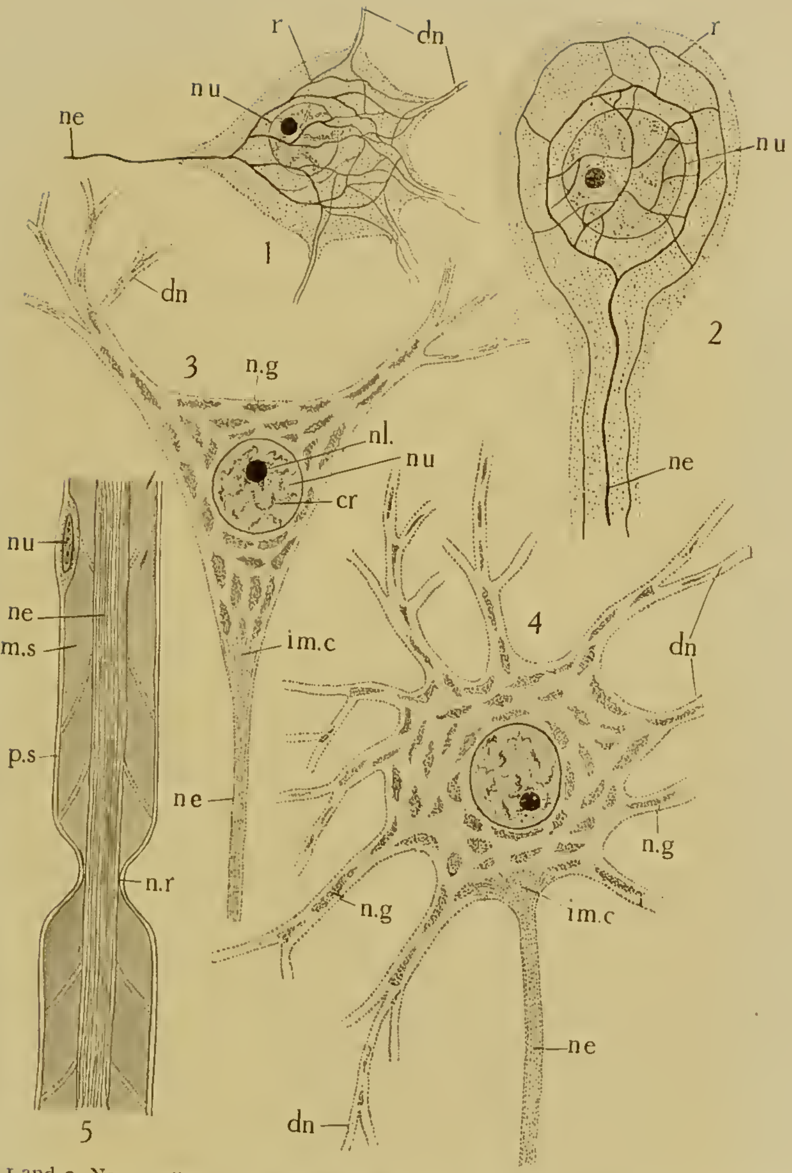
[1] For meaning of these terms see chapter on Karyokinesis.



Figs. 1 and 2. Nerve cells of a Leech, showing the delicate reticulum (**r**) of nerve fibrils traversing the cytoplasm of the cell. Figs. 3 and 4. Multipolar nerve cells from the spinal cord of an Ox, showing the Nissl granules (tigroid bodies) (**n.g**) in the cytoplasm of the nerve cell. Fig. 5. Portion of a medullated nerve fibre. **cr**, chromatin in nucleus; **dn**, dendrons; **im.c**, implantation cone of neuraxon (axon); **m.s**, medullary sheath; **ne**, neuraxon (axon); **n.g**, Nissl granule; **nu**, nucleus; **n.r**, node of Ranvier; **p.s**, primitive sheath of Schwann; **r**, reticulum of neurofibrils in cytoplasm of nerve cell.

absent in others; they occur in the dendrons (dn), but are absent in the axon or axis cylinder (ne). They apparently are so situated in the cell and its processes as never to interfere with the continuity of the nerve fibrils or nerve paths.

In some nerve cells pigment is normally present, but its function is unknown. It tends to increase with age and in he course of some diseases.

There are some nerve cells which are closely invested with a very delicate membranous reticulum, and which is sometimes called the **reticulum of Golgi.** It is possible that, as our methods of preparation become more refined, this investng sheath may be demonstrated in most nerve cells. The nerve cells of the ganglia, on the dorsal root of the spinal nerves, are ensheathed in a cellular and nucleated sheath. This sheath becomes continuous with that of the nerve of each cell.

We may distinguish between two kinds of processes arisng from the body of nerve cells. There are the **dendrons** (dn), which may be numerous, and the **neuraxon, axon,** or **axis cylinder** (ne), which is usually single. The dendrons re as a rule extensively branched (Plate IX, Figs. 3 and 4), nd their ramifications remain within the domain of the entral nervous system, *i.e.*, spinal cord and brain. They may transmit either afferent (inward) or efferent (outward) npulses. The neuraxon is, generally speaking, unbranched, nd it leaves the central nervous system to become the axis ylinder of a medullated nerve, or, in the case of a non-medullated nerve, it becomes the nerve itself. It, too, may ansmit either efferent impulses (as in motor cells) or afferent (as in sensory cells). Though we may regard it as relatively nbranched, yet this is not literally the case; for, at certain oints (Text-fig. 65, 4 and 5), very fine filaments, called colterals, arise from it almost always at a right angle. The euraxon arises from the body of the cell, in most instances, a special point, called the **cone of origin** or the **implantaon cone** (Plate IX, Figs. 3 and 4, im.c). This cone is characrized by a fibrillated appearance and by the absence of issl granules.

Some of the nerve cells of the brain may be divided into two types, according to the nature of the neuraxon. There is the **type I of Golgi**, in which the process (ne) possesses only a few collaterals and passes out beyond the area of the central nervous system (Text-fig. 65, 5). **Type II of Golgi** is characterized by a much-branched neuraxon (ne), the branches of which do not leave the brain (Text-fig. 65, 4).

Nerve cells are in physiological connection with each other by their dendrons. The ramifications of these do not apparently fuse, but are merely very closely approximated. The nerve impulse must "jump the gap" between them. This condition is spoken of as a **synapse**, But in some cases the dendrons of one cell, instead of forming a synapse with an adjacent one, become intimately incorporated with the external layer of the cell body. This condition is designated the "**Concrescence of Held.**" In other cases, the dendrons invest a nerve cell but do not appear to become anatomically continuous with it.

THE STRUCTURE OF NERVES

Nerves are usually classed as the **medullated** and the **non-medullated.** In the latter the axis cylinder or neuraxon of the cell remains naked or unenclosed in a sheath. We find such nerves in the sympathetic system.

The cranial and spinal nerves are for the most part medullated nerves. Each nerve fibre or axis cylinder (Plate IX, Fig. 5, ne) is enclosed in two sheaths. The inner (m.s) is fatty in composition and is broken up into regular segments. Each segment contains a nucleus (nu). This sheath is called the medullary sheath. Under the influence of various reagents it shows varying appearances. It is possible that these differing appearances are not expressions of real things, but are artifacts due to the reagents.

Externally, the fatty sheath is invested by a somewhat tough, structureless thin investment called the **primitive sheath of Schwann** (p.s). At the points where the medullary sheath is interrupted, the primitive sheath is constricted. These constrictions, or interruptions, which occur at regular intervals, are the **nodes of Ranvier** (n.r).

CHAPTER XXVII

KARYOKINESIS OR MITOSIS (CELL DIVISION)

ALL cell divisions are accompanied or preceded by the division of the nucleus; and while the cell protoplasm may, in some cases, lag behind the nucleus in its division, it never precedes it. When cells multiply by division, they do so in one of two ways. Either the nucleus simply fragments into two, the parts retreating from each other to either pole of the cell, or complicated changes ensue within the nucleus as a preliminary step to the actual division. The first type of nuclear division occurs in the meganucleus of *Paramœcium*, in nutritive gland cells, and frequently in degenerating tissues. It is, however, not of widespread occurrence in the higher animals, though among lower forms it may regularly appear in some part or another of the life-history. This direct method of nuclear division may be termed **Amitosis.** The indirect method is called **Karyokinesis** or **Mitosis.** It is of nearly universal occurrence, and the nature of its changes implies a significance of wide biological import. Within the phenomena of mitosis centres the explanation of the most fundamental processes of living organisms. Here, in large measure, we seek for further insight into the problems of variation and of inheritance, and every question pertaining to these phenomena carries us at once into the deeper aspects of organic evolution. The student will therefore approach the study of mitosis with a keener interest than pertains to any other branch of Biology. For in the processes of karyokinesis lie answers, not of limited application, but of the widest, extending from *Amœba* at one end of the living scale to Man at the other.

To properly appreciate the sequence and physiological importance of the events in a mitotic nuclear division, it is necessary to consider the detailed structure of the so-called "resting" nucleus. Externally it is limited by a thin, structureless **nuclear membrane** (Plate X, Fig. 1, n.m). The origin of this is at present somewhat obscure. There are reasons justifying us in believing that it is of cell origin, and is formed as a sort of precipitation membrane from the cytoplasm. In some of the sporozoic protozoa (*Coccidia*), however, it is possible that in part at least it is of nuclear origin, and is partly formed by contributions of chromatin from the nucleus. Occupying the cavity of the nucleus and enclosed by the nuclear membrane is a gelatinous substance called **paralinin** or nuclear sap[1] (nu.s.). Embedded within this is a meshwork of denser substance, the **linin reticulum** (Figs. 1 and 2, l.r). Included within the linin network are numerous minute granules of a substance which stains more deeply than any other within the nucleus, and hence is spoken of as **chromatin** (Fig. 1, chr). It is highly complex chemically, containing nitrogen and phosphorus. Upon analysis it can be made to yield proteins and nucleic acid. There is evidence, largely derived from its behaviour towards staining reagents, that chromatin undergoes chemical changes during the course of karyokinesis. This, however, is not at all certain, and the various appearances which it presents may be explained by the increasing amount of concentration which occurs among its granules in certain stages of mitosis. In addition to the chromatin granules, which are confined to the linin network, there are present one, two, or more much larger grains, called the **plasmosomes** or **nucleoli** (nuc). Generally speaking, especially for the higher forms of animals and plants, the nucleoli are devoid of nuclein, and thus chemically differ from the chromatin. It is probable, however, that more than one kind of nucleolus exists, for in the lower forms of life, in addition to the nucleoli which are devoid of nuclein, others composed of a substance allied to it certainly exist also. Nucleoli stain less intensely than the chromatin grains. Their behaviour during nuclear division is very significant and pretty uniform. Upon the onset of mitosis their substance becomes vacuolated, and eventually breaking up into fragments (Figs. 2, 3 and 4), disappears altogether as mitosis advances. It is probable, therefore, that they serve as reservoirs of nutritive substances from which the material and energy necessary for karyokinesis are derived. Other bodies, the **karyosomes**, approaching the nucleoli in point of size, are sometimes present within the nucleus. These bodies, however, are concentrated masses of chromatin grains, and in the life-history of some forms of parasitic protozoa play a conspicuous and constant part.

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[1] Another term is **karyolymph**.

Closely related to the nucleus, though lying outside it, are the **centrosomes** (cent). They appear to be absent from the cells of some plants and some animals. When present, each resting nucleus may have one or a pair of centrosomes. They lie in a globular body, called the **attraction-sphere** or **astrosphere** (ast). From the astrosphere, especially after mitosis has begun, a number of fine lines radiate into the cell protoplasm, producing the **astral-figure** (ast.fig and ast).

The whole of the contents of the nuclear membrane are sometimes collectively called the **karyoplasm**,[1] in distinction to the term **cytoplasm**, which is applied to all the cell material outside the nucleus.

In the resting nucleus (Fig. 1, chr) the chromatin granules are dispersed throughout the linin reticulum. One of the earliest indications of commencing karyokinesis is the loss of this scattered condition and the arrangement of the granules in a linear series along the fibrils of the linin substance (Fig. 2). The linin meshwork, in stained preparations, now presents the appearance of a very definite and deeply stained tangled or coiled thread, on account of the regular arrangement of the deeply staining chromatin within it. The meshwork begins to contract and a coiled thread, sometimes called the **spireme-thread**, is formed (Fig. 3). Within this the chromatin grains are arranged in a single row. The loops of this become fewer in number,

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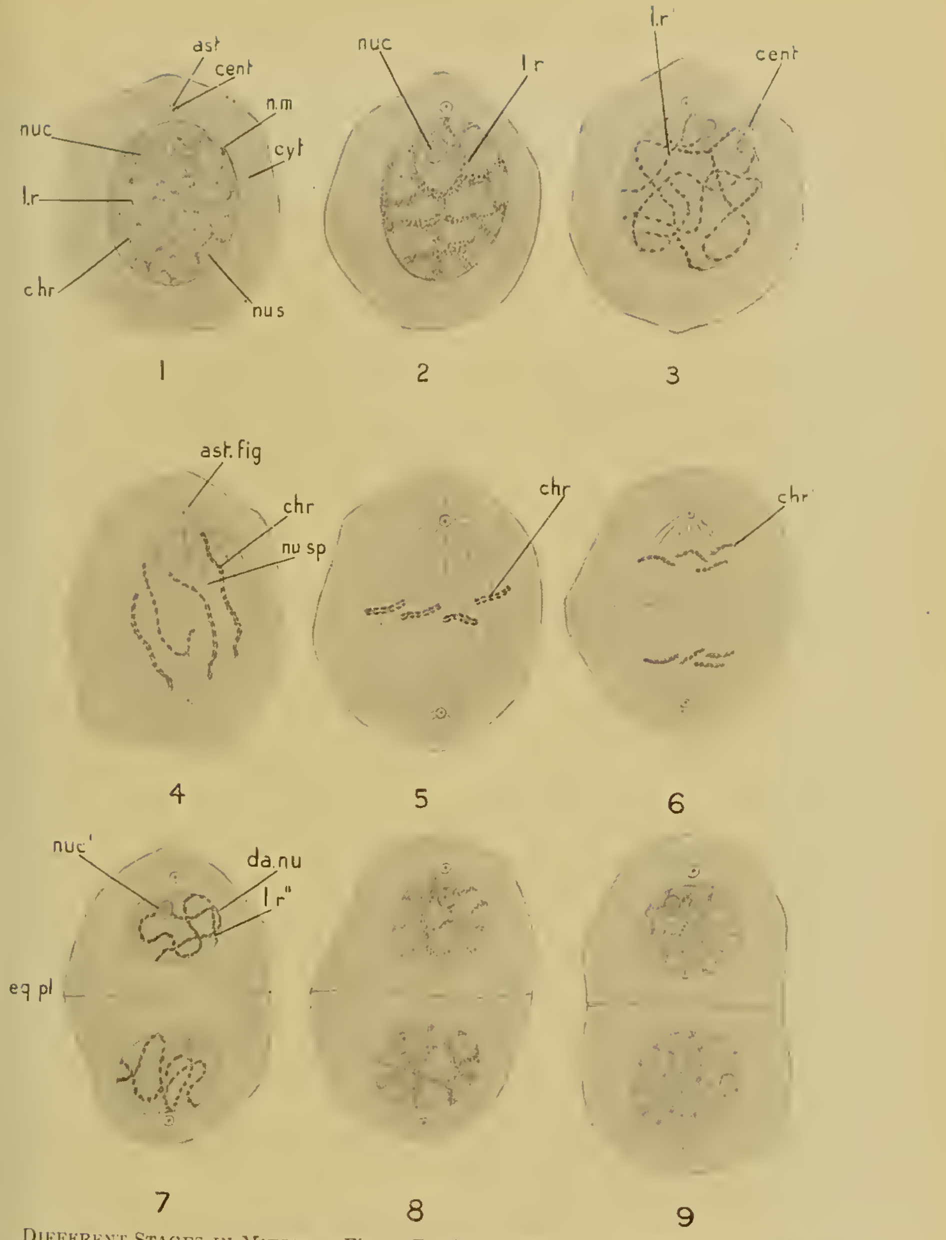
[1] An alternative term is **nucleo-plasm.**

and the thread then breaks up into a number of segments or **chromosomes** (Fig. 4, chr). These usually assume a horseshoe shape, but in some species they are simple, straight rods in form. The number of chromosomes is usually constant in any particular species, though it varies with different species. In a threadworm (*Ascaris megalocephala*, *var. univalens*) there are only two. In a crustacean *Artemia* there are 168. In the spotted Salamander and in the Lily the number is 24. The chromosomes, after they are formed, continue to shorten and thicken and to arrange themselves in the equator of the nucleus (Fig. 5). While these changes have been going on, two other events have occurred. First, the centrosphere divides into two (Fig. 3), and they mutually move apart until they reach opposite poles of the nucleus (Fig. 4). Second, the nuclear membrane and the nucleoli disappear. Shortly after the division of the centrosphere a number of lines radiating from them make their appearance (Fig. 4). By the time the two centrospheres have taken up their polar positions, it is seen that part of these radiations spread out into the cell protoplasm, and may be termed the **astral rays** (astr, Fig. 4). But a part also extends inwards through the nuclear substance, where it meets the corresponding portion of the rays of the opposite centrosphere, in the nuclear equator. A spindle-like body is thus formed, stretching between the two centrospheres, and composed of what are regarded as extremely delicate fibrils (nu.sp). This part of the nuclear mechanism is called the **nuclear spindle.** Some of the fibrils of the spindle, called the **mantle fibres,** become attached to the chromosomes ; those which remain unattached are termed **spindle fibres.** A very curious and significant phenomenon now takes place. Each chromosome splits into two along its length (Fig. 5). It is very necessary to notice that the division is longitudinal and not transverse. The significance of the process would be quite different if the splitting was across and not along the chromosome. In order to fully understand the nature of this splitting we must carefully bear in mind the essential structure of the chromosome. It is a rod of linin substance in which a single row of chromatin

PLATE X



Different Stages in Mitosis.—Fig. 1. Resting nucleus. Chromatin evenly distributed. Fig. 2. Nucleus showing more marked reticulate structure. The linin in thick strands. Fig. 3. The linin much contracted and now forming thread-like meshes. Chromatin granules arranged in a single row in linin thread. Fig. 4. Division of spirem thread (linin network) into a number of chromosomes; the chromatin granules (chromomers) have each divided and are arranged in two rows instead of one. The nuclear spindle has formed. Fig. 5. Contraction and thickening of the chromosomes; they are now arranged on the nuclear equator and are attached to the mantle fibres. Fig. 6. Each chromosome has split longitudinally, and the two halves have respectively passed to opposite nuclear poles. Fig. 7. The chromosomes are merging with each other and forming the spirem thread of the daughter nuclei. The nuclear membrane and nucleoli have reappeared. The equatorial plate is formed. Fig. 8. The linin thread (spirem thread) is thickening. Fig. 9. The daughter nuclei are now in the resting condition, and show an even distribution of the chromatin. **ast**, astrosphere; **ast. fig**, astral figure; **cent**, centrosphere; **chr**, chromatin, chromatin granules, or chromomeres; **chr^{1}**, chromomeres of daughter chromosomes; **cyt**, cytoplasm; **da.nu**, daughter nucleus; **eq.pl**, equatorial plate; **l.r**, linin reticulum; **l.r^{1}**, linin or spirem thread; **nuc**, nucleolus; **nuc^{1}**, nucleolus of daughter nucleus; **n.m**, nuclear membrane; **nu.sp**, nuclear spindle.

granules,[1] or **chromomeres**, as we shall now term them, are serially arranged (Plate X, Fig. 4). Before the linin substance splits each chromomere divides into two. At this stage, therefore, the chromosome contains two rows of chromomeres instead of one (Plate X, Fig. 5, and Text-fig. 66, y). In some cases (as in that shown in our plate Figs.), however, the division of each chromomere takes place before the formation of the chromosomes, and occurs in the spireme thread (Figs. 3 and 4). In such instances the chromosomes contain the double row of chromomeres from the moment of their formation (Figs. 4 and 5). The linin substance of the chromosome now divides longitudinally in a plane passing between the two rows of chromomeres, and two daughter chromosomes result from each mother chromosome (Plate X, Fig. 6, and Text-fig. 66, z). But the two daughter chromosomes contain a chromatin content (chromomeres) which is identical in nature. This necessarily follows from the single serial arrangement and bisection of the chromomeres. If we suppose a given chromosome (Text-fig. 66) contains chromomeres of the nature indicated by A, B, C, D, E, and F, &c., each of which divides into two, then both daughter chromosomes will contain chromomeres of the same nature, *i.e.*, A, B, C, D, E, and F, &c. This duplication or reproduction of the chromatin grains (chromomeres) is the central feature of karyokinesis.

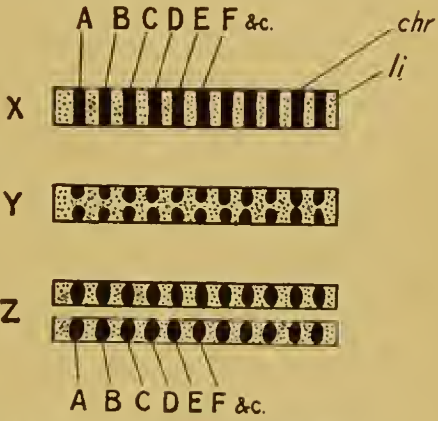


FIG. 66.—Chromosomes dividing. **X.** A chromosome showing the single row of chromomeres (chromatin beads, chromatin plates). **Y.** The chromomeres have each divided into two, and the chromosome contains a double row of chromomeres. **Z.** The chromosome has split longitudinally through the linin substance in a plane between the two rows of chromomeres and two daughter chromosomes are formed. Each necessarily contains the same chromatin (chromomere) content. **chr.** Chromomeres. **li.** Linin substance of chromosome. **A, B, C, D, E, F,** &c., symbolically represent qualities carried by the chromomeres.

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[1] These are the *ids* of Weismann's hypothesis.

The splitting of the chromosomes occurs while they are arranged in the equator of the nucleus. Upon the formation of the daughter chromosomes the mantle fibres begin to contract and pull the two halves apart towards the opposite poles of the nucleus (Fig. 6). The chromosomes thus carried up to one pole are in their chromatin contents simply duplicates of those carried to the opposite pole (Fig. 7). Thus concentrated in the two polar regions the chromosomes begin to branch and to run together, forming again the linin meshwork of a resting nucleus (Figs. 8 and 9, l.r″). At about the same time the nucleoli and the nuclear membrane reappear, and two resting daughter nuclei (da.nu) are formed. Across the equator of the cell, in a plane midway between the two newly constituted nuclei, a granular plate of protoplasm, termed the **equatorial plate** (Figs. 6 and 7, eq.pl), is formed. Along this plate the cytoplasm eventually divides (Figs. 8 and 9) and two cells each containing its own nucleus result. Thus from the single parent cell, two daughter cells, identical as far as we can perceive with each other and with the mother cell, are produced. They are at first smaller, but apart from this feature the daughter cells in essential attributes are, as it were, the mirror-images of the parent cell. The difference turning upon size soon disappears by the growth of the young cells.

Hidden away within this complicated process of mitosis there lies some definite meaning. While the details of karyokinesis in different species of animals and plants vary very widely, the central feature in all cases appears to be the duplication and equivalent distribution of the chromatin grains. Their duplication by division may occur at very different times in the nuclei of different organisms, but throughout a great variation in the details of the other processes of nuclear division, the one constant feature of the phenomena is this binary division of the chromatin grains and of the chromosomes. And, as far as we know, each grain divides into two, and not into three or four or more. Each one of these two grains is carried into opposite daughter nuclei, one grain into one nucleus and its fellow to the other, When an epithelial cell divides it produces two daughter epithelial cells ; when cartilage cells divide they each beget two cells like themselves. Not only do "cells come from cells," but specific kinds of cells produce like cells. Now an epithelial cell differs from a muscle cell. Upon what do the differences depend? Since "like begets like," we must seek the source of these differences, as we must also seek the source of the specific properties of the cells themselves, within the cell. They are inherent and are not impressed from without. If these specific characters be transmitted from one cell generation to another, are they carried in some material substance, and if so, what is this substance? And if these characters are transmitted by some material body, then their manifestation in the cells depends upon the presence of this body within the cell. Now it is in the attempt to answer these questions that we find a rational meaning of the processes of nuclear division and an intelligible conception of the place of chromatin in the scheme of things. It probably is the substance which carries the qualities of cells through successive generations and excites the manifestation of these specific qualities as manifested in the form, size, and other morphological and physiological attributes of the cell.

For purposes of description we may recognize four periods in the series of changes which constitute mitosis. (1) **Prophase.** (2) **Metaphase.** (3) **Anaphase.** (4) **Telophase.** The Prophase period. This comprises all the changes up to the formation of the chromosomes, the nuclear spindle, and the disappearance of the nucleoli and nuclear membrane (Figs. 1–4). The Metaphase period. This includes the arrangement of the chromosomes upon the nuclear equator and their longitudinal splitting (Fig. 4). The Anaphase period. The passage of the sister chromosomes to their opposite poles constitutes the anaphase (Fig. 6). In the next period, the Telophase period, the aggregated chromosomes at either pole run together and give rise to the linin reticulum of the new resting nucleus (Figs. 7–9).

CHAPTER XXVIII

MATURATION OF THE GERM CELLS

THE cells which constitute the body of a Metazoan fall naturally into two groups, *i.e.*, the **somatic** or **body cells** and the **gametes** or **sex cells**. There is a fundamental difference in the nuclear contents of the cells of these two groups. We have seen that the number of chromosomes, though varying widely for different species, is constant for the cells of any particular species. Whatever the number may be in the somatic cells (such as epithelial cells, muscle cells, nerve cells, and the like), it is, with a certain definite exception, half that number in the sex cells. The series of changes by which this reduction from the somatic to gametic number is brought about, are collectively designated by the term "**maturation of the germ cells.**" The nuclear divisions which are concerned with this numerical reduction of the chromosomes, constitute a somewhat definite phase in the general series of cell divisions that make up the morphological life-history of the organism. It has therefore been termed the **Maiotic phase.** All the series of cell divisions which precede it, beginning with the segmentation of the fertilized ovum, are included in a **Pre-maiotic phase,** and those which succeed it belong to the **Post-maiotic phase.** The two first phases are essentially the same in animals and plants. But in animals there is no post-maiotic stage, this being confined to the sexual generation or gametophyte of plants. In the flowering plants this generation is found within the embryo-sac and pollen grains, and in the flowerless plants in the prothallium.

In many important details the maturation of the germ cells varies in different organisms. All that we can hope to do here is to present in a more or less generalized form an account of some particular type.

We will suppose that we are dealing with the maturation of the germ cells in a species having somatic nuclei with four chromosomes. This number is chosen because it is a convenient one to deal with. (Plate XI, Figs. 1–8 and A–D.)

The somatic cells which are destined to eventually become sex cells, are not at first distinguishable from the ordinary somatic cells. They may for convenience be called the **primitive sex cells.** At a certain stage they cease to multiply and grow considerably, their nuclei passing into the resting condition, preparatory to the maiotic phase. These cells are the **sex mother cells.** The maiotic mitosis is then ushered in by the closer, more chromatic and often polarized arrangement of the spirem thread (linin reticulum) (Fig. 1). The polarization increases and the chromatin becomes arranged in a number of loops, instead of being continuously distributed throughout the thread. The number of these loops is then seen to be one-half that of the chromosomes present in the nuclei of the somatic cells (Fig. 2). There is little doubt that each of these loops represents two somatic or univalent chromosomes joined end to end at the bend of the loop. They are therefore bivalent. The chromatin grains, which are at first arranged in a single row in the loops, then divide into two, so that a double row of chromatin beads (chromomeres) replaces the originally single row (Fig. 3). This double-beaded phase of the loops may last for some time. It represents a longitudinal splitting of the chromosomes which, instead of immediately completing itself, is inhibited for the time being, since the two halves do not at once separate. In some cases both this longitudinal splitting, and also the transverse separation which here occurs, as we shall see a little later, is completed at this stage and then the sex mother cells contain twice as many chromosomes as the somatic cells. But here the individual loops contract, thicken, and shorten, in the course of which the longitudinal fission closes up and disappears (Fig. 4). The loops or, as we may term them, the

maiotic chromosomes[1] now arrange themselves in the equator of the nucleus. At about this time the nuclear membrane and nucleoli disappear. The loops then become divided into two halves by a transverse fission at their bend (Fig. 5). Each half represents a separate and independent somatic chromosome. This transverse division of the loops into two represents the completion of the partially belated separation of the chromosomes from their spirem thread. Instead of the spirem thread giving up its full number of chromosomes at once in the earlier stage, as in an ordinary somatic mitosis, it does it in two stages, of which the transverse division of the loops is the second stage, the formation of the loops being the first. By this transverse division the number of chromosomes is now raised to its full somatic number, *i.e.*, in this case four.[2] The chromosomes next became sorted out into two groups, one passing up along the nuclear spindle to one pole of the nucleus, and the other downwards to the opposite pole (Fig. 6). The manner of this distribution is of particular importance. Each maiotic chromosome or loop, as we have seen, was really bivalent, that is, it represented two somatic chromosomes united together end to end. But by its transverse division the two associated somatic chromosomes are liberated. Now the manner of distribution which we are considering is of such a nature that the two associated chromosomes of each pair do not pass to the same pole of the nuclear spindle, and therefore are not found later on, when the mitosis is completed, in the same daughter nucleus. But instead, they pass to opposite poles and therefore into separate nuclei when the nuclear division is finished. Each daughter nucleus thus receives different contingents of chromosomes. The important point to notice is that this distribution is of *different* chromosomes, not of the *halves* of the *same* chromosomes. It thus differs fundamentally from

[1] An alternative term in general use is **heterotype chromosomes.**

[2] It should be noted that if the longitudinal split had become completed at this or an earlier stage, there would now be eight chromosomes present, *i.e.*, twice the somatic number. In some cases, as in the threadworm, (*Ascaris*), and in others, this actually occurs. In the type we are considering, this longitudinal split is not completed until a later phase.

that of an ordinary somatic mitosis. The number of chromosomes is thus reduced both quantitatively and qualitatively by this mitosis. It is therefore spoken of as the **true reduction division** or **first maiotic division,** to distinguish it from the one which follows and which is quantitative only.

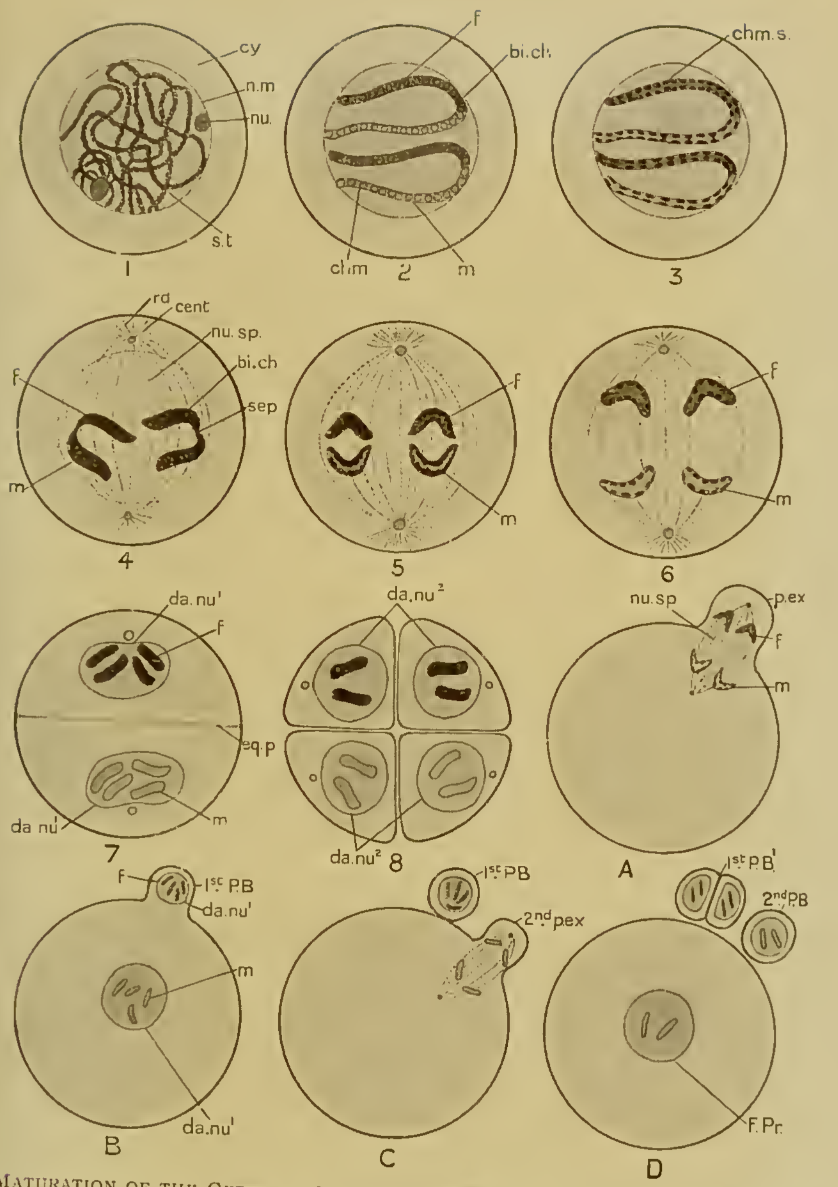
While this distribution of *whole* chromosomes is going on and often before they are transversely segmented from the maiotic loops, the original longitudinal split (Fig. 3) which was transiently present in the spirem loops reappears (Fig. 6). It becomes completed as the univalent chromosomes are passing to the poles of the nucleus. This division really anticipates the longitudinal splitting of the chromosomes at the next or second maiotic mitosis. A nuclear membrane now reappears, and two daughter nuclei are formed (Fig. 7).

We must be careful to recognize the fact that though each of the two univalent chromosomes splits longitudinally and becomes paired, the actual number of *specific* chromosomes resulting from the first reduction division is not four but two. The four which are actually present only represent the twinned halves of two separate chromosomes.

The characteristic feature of the particular mitosis we are considering is the **qualitative** as well as quantitative **reduction** brought about by the bodily distribution of different chromosomes to the two daughter nuclei.

By the time the first reduction division is completed the position is as follows: Each of the two daughter nuclei, resulting from the division of the sex mother cell, contains four chromosomes; these represent the twinned halves of two different chromosomes. If the next mitosis, which is known as the **second reduction division,** were of the ordinary somatic (pre-maiotic) type, each of these four chromosomes would split longitudinally, producing eight and giving four chromosomes to each of the resulting daughter nuclei. But we have already seen that this longitudinal splitting is anticipated during the latter part (metaphase and anaphase) of the previous mitosis. It does not therefore occur again, and the second reduction division *appears* to be like the first, *i.e.*, merely a *sorting* out of the chromosomes of the mother nucelus into the two daughter nuclei. For the four chromosomes pass in two groups of two in each along the nuclear spindle to opposite poles without undergoing any concurrent longitudinal splitting. But in reality no sorting out occurs, since the distribution is of twinned halves of chromosomes into their two respective daughter nuclei, one half of a chromosome passing into one daughter nucleus and the other half into the corresponding nucleus (Fig. 8). Each daughter nucleus now contains only two chromosomes, or half the somatic number. The reduction which has occurred, however, is quantitative only, not qualitative. There are, however, cases where the qualitative reduction occurs during the second maiotic division, the first being quantitative only.

Let us now briefly recapitulate this somewhat complicated process. The spirem thread after polarization breaks up into two maiotic loops or chromosomes. Each of these is bivalent and represents two somatic chromosomes cohering together, end to end. Just previous to this, or at this stage, the spirem thread shows a split and double-beaded appearance due to the binary division of the chromomeres. The looped bivalent chromosomes now contract and thicken, and the split closes up. Each then becomes transversely divided into two univalent chromosomes. The nucleus now contains the full somatic number. The chromosomes arrange themselves on the equator of the nuclear spindle, and the longitudinal split reappears. They are next carried apart in two groups along the nuclear spindle to opposite poles. This distribution is qualitative, *i.e.*, different chromosomes—not halves of the same chromosomes—are carried to the nuclear poles. A nuclear membrane appears around each group, and two daughter nuclei are formed. Each very quickly divides again, by a simple assortment of the halves of the split chromosomes derived from the last mitosis. This second reduction division is in reality an ordinary somatic (pre-maiotic) mitosis in which, however, the longitudinal splitting of the chromosomes occurred during the previous mitosis, but without any concurrent distribution into separate daughter nuclei of the split halves. That occurs only at this last mitosis. Four



MATURATION OF THE GERM- OR SEX-CELLS.—Figs. 1 to 5 represent the stages common to the maturation of both egg-cells and sperm-cells. Figs. 6 to 8 are the stages special to the sperm-cells Figs. A to D are the stages special to the egg-cells. **bi.ch**, bivalent chromosome; **cent**, centrosphere; **chm**, chromomere; **chm.s**, chromomeres split; **cy**, cytoplasm; **da.nu^1**, daughter nucleus of first reduction division; **da.nu^2**, daughter nucleus of second reduction division; **eq.p**, equatorial plate; **F.Pr**, female pronucleus = nucleus of ripe egg; **f**, the maternal moiety of bivalent chromosome; **m**, the paternal moiety of bivalent chromosome; **n.m**, nuclear membrane; **nu**, nucleolus; **nu.sp**, nuclear spindle; **r.d**, astral radiations; **p.ex**, first polar extrusion = origin of first polar body; **sep**, point of transverse separation of the two monovalent constituents of the bivalent chromosome; **1st P.B**, First polar body; **1st P.B^1**, First polar body after division; **2nd P.B**, Second polar body; **2nd p.ex**, Second polar extrusion = origin of second polar body.

cells are thus formed from every primary sex cell, and the nucleus of each contains only two chromosomes, *i.e.*, half the somatic number. These four cells in the case of plants will be spores or pollen grains, and in the case of animals they will be spermatozoa.

A few general considerations may be considered at this point. At the first reduction division the two nuclei formed contain different chromosomes, and are thus of different hereditary value. It is at this division apparently that alternative maternal (Figs. 5, 6, 7, f) and paternal (m) characters are segregated and passed into different cells. The two daughter nuclei formed at the second reduction division from each of the two nuclei of the first reduction division, merely carry the halves of the same chromosomes and are thus of equivalent hereditary value.

Thus in respect to any particular character factor, two of the four cells will be carrying the maternal contribution and two the paternal. In other words, of the total number of the sex cells of an organism, one half will carry the maternal and the other half the alternative paternal contribution. Such conceptions must serve to profoundly alter some of our previous views of heredity. For if the chromosomes or the still smaller units, the chromomeres, are the carriers of the hereditary substances which influence the manifestation of zygotic characters, then it seems clear that paternal and maternal characteristics are not blended but segregated. That being so, there can be no modification, through the mechanism of inheritance, of qualities passed on from one generation to another. Paternal red-hairedness is not darkened by maternal brunetteness nor *vice versa*. In the descendants of those parents, red-hairedness and brunetteness may reappear as in the father and the mother.

The account which has been given of the two reduction divisions is in all its essential features true of many plants (Lily, Royal Fern, *Psilotum*, *Aneura*, &c.) and animals (cockroach, fishes, amphibia and mammals), including Man. And, though there are departures from the type we have described, yet on the whole it represents a process of fundamental significance and of wide extent in the living kingdom as a whole.

The details of the process as they have been described above are specially applicable to the maturation of the male sex cells. They are illustrative of the formation of the pollen grains and spores in plants and of spermatozoa in animals. We may here mention that when the sex mother cells are destined to become male sex cells they are called **pollen mother cells** in plants and **sperm mother cells** in animals.

In essential features the maturation of the egg-cell or ovum is similar to that of the male sex cells. There are, however, important differences in detail. We may consider what happens in an animal egg-cell. The maturation is the same up to the formation of the sex mother cell. This will now be known as the **egg mother cell.** Instead of dividing at the first reduction division into two cells of equal size, it divides into one large one and a very small one. This latter is the **first polar body** (Plate XI, Figs. A and B). The larger cell will become the ripe egg. The second reduction division almost immediately follows the first and a **second polar body** is formed (Fig. C). The behaviour of the chromosomes and their numerical and qualitative reduction, at each division, is the same as the corresponding divisions in the male cells. In many cases, while the second polar body is being extruded, the first divides into two (Fig. D). In all four cells are thus produced. Three are very small and non-viable and one only is large and viable. The latter is the ripe egg. Each of the four cells, like the four viable male cells, contains only two chromosomes. The matured egg—the female gamete—thus possesses, like the male gametes, only half the somatic number of chromosomes.

Since the first reduction division of the egg mother cell is essentially the same as that of the sperm mother cell, which, as we have seen, is a qualitatively reducing division, it follows that the first polar body contains one set of different chromosomes and the egg cell the other set. Now if for the sake of illustration we call these two sets *f* and *m*, and we assume that the extrusion of the *f* or *m* set of chromosomes into the polar body is a matter of chance, it follows that sometimes it will be *f* and sometimes *m* which is extruded. Now, on an average, *f* and *m* will go out an equal number of times, and therefore two sets of ripe eggs, each equal in number, will be formed. One set will be carrying the *f* chromosomes and the other set the *m* chromosomes. In other words, the alternative paternal and maternal characters may both be present in the gametes of the same individual, but carried in different sex cells. It is this conception which we understand when we use the term **gametic purity.**

We have now reached the stage when the male and female sex cells are ripe and ready for fertilization. Both are characterized by the reduced number of chromosomes. Both in the course of their maturation have eliminated alternative maternal and paternal characters.[1] Each carries, as a consequence, either the maternal or paternal alternative character but not both. Now fertilization, in essential features, is simply the fusion of a male and female sex cell. This fusion involves the union of the two nuclei. With but one or two exceptions the egg cell is passive throughout the animal and plant kingdoms and the sperm cell is actively motile. It reaches the egg by its own motility and penetrates its substance. While the egg contains relatively much protoplasm, the sperm cell (spermatozoa) is practically nearly all nucleus. Its nucleus indeed is ensheathed in a mere film of protoplasm, which is drawn out behind into a protoplasmic filament, by the movements of which motility is imparted to the cell. When the sperm cell enters the egg its tail is lost or absorbed in the cytoplasm of the egg-cell and its nucleus is then known as the **male pronucleus.** The nucleus of the egg is the **female pronucleus.** The two pronuclei appear to be mutually attracted, for they approach each other and unite. The common nucleus thus formed is the **segmentation nucleus.** Here we must be careful to make an important distinction. While the two pronuclei fuse their contained chromosomes do not. Those brought into the segmentation nucleus by the male pronucleus, while they lie side by side with those contained in the female pronucleus, do not fuse with them. There is thus no blending of the maternal and paternal characters, so far as the behaviour of the chromosomes is concerned.

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[1] More strictly speaking the chromatic substance which by its presence influences the manifestation of characters.

The formation of the segmentation nucleus ushers in a new phase. The fertilized egg divides up repeatedly for some time to come and builds up a new organism. The fusion of the two sexual pronuclei has of course restored to the segmentation nucleus the full somatic number of chromosomes. It contains four of them. During the subsequent divisions by which the embryo is produced, the mitosis is of the ordinary somatic or pre-maiotic type. At each division the chromosomes are split longitudinally and no reduction in number occurs. From the moment of fertilization we speak of the new individual thus formed as the **zygote.** The zygote is the product of the fusion of two gametes.

CHAPTER XXIX

THE DEVELOPMENT OF ORGANISMS

FORMATION OF THE GERMINAL LAYERS

The Early Embryology

THE animals we have examined form in a sense an ascending scale. The frog is higher than the dog-fish, the dog-fish than the worm, the worm than hydra, and hydra than amœba. No doubt each of them is equally fitted to the circumstances in which it lives, and, so far as what is called **adaptation to its environment** goes, each is equally well off, and the frog, for instance, would be as unable to occupy the place of amœba as amœba would be for the manner of life of the frog. But in the type of its structure, each of them forms an improvement and advance on the one next below. Hydra is a colony of single cells which are specialized and arranged so as to form the cœlenterate type of structure. The cœlomate type is an extension and improvement on the cœlenterate, while among the cœlomata the vertebrate type is composed by a series of alterations of and additions to a simple invertebrate type. Among the vertebrates we have seen that the type on which the frog is built is in many respects simply an improved and altered edition of the dog-fish type. It must be remembered, however, that we have examined only three or four out of the multitude of forms composing the animal kingdom; and each kind of animal, in addition to its ground-plan, its typical structure, has an immense number of individual characters. It is only after the examination of a larger number of animals that it is possible in individual cases to separate the structures of the animals that are individual peculiarities from the structures which characterize its type or race. Every one has seen the immense blocks of buildings divided into hundreds of sets of flats that are now being erected in our large cities. There are generally only three or four types of suites of rooms among all these sets. But before they are occupied one may see a legend on a placard stating that these flats will be "papered and decorated to suit the wishes of the tenants." When this has been done the different tenants have their own ideas of furniture, of arrangement of pictures, and so forth, and when the whole block is occupied perhaps only an architect could discern among all the diversities of appearance the three or four ground-plans of structure that exist. The animal kingdom in many respects is like this. But the amœba, the hydra, the earthworm, the dog-fish, and the frog, have been selected because they are representatives of the leading types of structure that have been found to exist among animals.

The embryological development of an animal is the series of changes through which it passes from its first formation to its arrival at the adult type. It will be remembered that even in the protozoa there were instances of changes of this nature. For instance, when *Vorticella* reproduces by spore formation, the tiny, naked, nucleated mass of protoplasm that emerges through the ruptured spore-wall bears no resemblance to the adult condition. It feeds and grows, develops cilia and swims about. At last, however, it forms a pharynx, peristome, and disc, and, becoming fixed by a contractile stalk, settles down as an adult *Vorticella*. However, the young cell creeping out of the spore is as much a cell as the fully formed complicated animal. In the embryological development of all the metazoa the set of changes consists not only in the specialization of cells, but in their multiplication and arrangement in definite ways. It is now known that animals in the course of their development pass through stages corresponding to the main types of structure below them. Thus the sexual development of all the metazoa begins with the union of a male cell, or spermatozoon, with a female cell or ovum. This corresponds to the conjugation of two protozoa before spore formation. Next, by division of the cell resulting from the fusion of the male and female cells, a mass of cells is formed, sometimes solid, sometimes hollow, and this stage, the blastosphere, corresponds to a colony of protozoa. Next the blastosphere turns into a two-layered form such as the gastrula. The cœlenterate animals do not rise beyond this in type. *Hydra* is a simple modification of it, and the other cœlenterates are simply complications of the gastrula type. Next, the gastrula becomes cœlomate by the formation of the middle layer and the cœlome. Then a number of different courses may be followed. In a typical invertebrate a leading change consists in the concentration of the ectodermal nervous layer into a brain, a ring round the œsophagus, and a ventral ganglionated chain. In the typical vertebrate the ectodermal nervous layer becomes concentrated into a brain and dorsal nervous tube, while a skeletal structure, the notochord, appears between the gut and the dorsal nerve tube. At the same time the front end of the alimentary canal becomes modified in connexion with respiration by the formation of gill-slits.

We shall now consider the essential features in the earlier stages of the process of development. As we shall see later, every triploblastic metazoan traces the origin of its tissues to three primary or embryonic layers. These are called the **germinal layers.** The two first formed arise directly from the segmentation of the fertilized egg, and the third is a derivative of the other two, in greater or lesser part from the one or the other. It is with the formation of these germinal layers that we are more specially concerned.

A new organism, as we have seen in the case of the sexual reproduction of metazoa, is produced from the zygote resulting from the conjugation of an egg-cell and a sperm-cell. But as a matter of fact, the cell so formed derives its separate elements unequally from male and female. Practically all the protoplasm of the cell body is that of the female. The centrosome is usually that of the male. The nuclear matter consists of two chromosomes from the female and two chromosomes from the male. As a matter of common obsei vation, we know that children or animals inherit as mucl from their fathers as from their mothers. It is to be inferrec from this that if the inherited characters are conveyed by th male and female cells, and we know of no other way in whicl they could be conveyed, they are conveyed by some part o the sexual cells to which both parents contribute equally. I is the chromosomes of the nucleus which are equally contributed by both parents, in the figures each supplying two Accordingly, it is generally believed that the chromatin of the nucleus is the bearer of inherited characters.

The centrosome is almost certainly an organ of division. and, as we have seen, it may be derived simply from the male, although in some cases a centrosome is present in the ovum also. The protoplasm of the body of the egg alone is present in the fertilized cell. In one case it has been shown by actual experiment that it does not act as the bearer of maternal characters. A German investigator was able to remove the nucleus from the egg-cells of one species, which may be called species A. Then he poured over the eggs spermatozoa from another species, which we may call B. He found that the eggs developed into young embryos of the species B. As there was present only male nuclear matter, only the characters of the species to which the male belonged were transmitted.

We see, then, that the nucleus of cells has one important and special function. It is the part of the cell which, when the cell conjugates with another, or divides, is the bearer of the characters of the cell.

In addition to what has been mentioned, an important set of secondary structures are frequently developed around the egg. These serve as shells or membranes which protect the young embryo during the early stages of its growth. They are formed in very different ways, and there may be several of them present in a single case. The simplest is a cell-wall formed from the protoplasm of the egg itself. This is generally a very thin and delicate structure, but round about it other protective membranes may be formed, especially when, from the presence of much food-yolk, the egg is large and bulky. The follicle cells which surrounded the ovum while it was in the ovary may form a stout membrane or shell, which is often horny. Then, when the egg is travelling down the oviduct towards the exterior, the walls of the oviduct may form round it a gelatinous or albuminous layer. Lastly, sometimes from special glands in the lower part of the oviduct or in the uterus, an external shell may be added. Thus the egg of a fowl is surrounded by a series of membranes of this kind. In the ovary it arises as a small cell of microscopic size. Into this yolk is poured from the follicle cells, and round it is formed a delicate cell-wall by its own protoplasm. This, however, disappears after a very short time, and when the egg leaves the ovary it is surrounded by a special membrane formed by secretion from the follicle cells, and known as the **vitelline membrane.** When it passes into the upper portion of the oviduct, secreting cells pour round it the white-of-egg, or albuminous layer. In the middle region of the oviduct the outer part of the white-of-egg becomes hardened into the fibrous shell-membranes, and finally in the lowest portion of all the calcareous shell is deposited by a special set of cells. Of course, in different animals the nature and method of deposition of the egg membranes are different. Generally the entrance of the spermatozoon is effected before the formation of membranes, but in some cases a special aperture, **the micropyle,** is left in order to allow the entrance of the male cell. In such a case there is generally present only an inner, or vitelline membrane.

After fertilization of the egg has been effected, cell-division, or, as it is called in the case of the egg-cell, **segmentation** occurs. The simple nature of this as a case of cell-division is disguised in those cases where much food-yolk is present. In such the nucleus divides, but the division does not extend completely through the large cell body, bloated as it is with inert food-yolk. Thus, in the case of the dog-fish, or fowl, the division of the nucleus is followed only by a partial division of the body of the cell, this attempt at division being represented by a furrow or line of cleavage extending only a little distance into the surface of the yolk mass. As the presence of yolk complicates the method in which the subsequent stages of development take place, we shall describe the method of segmentation and development that occurs in cases where there is only a very small amount of yolk present in the egg. As all the divisions take place by the process of karyokinesis, which has already been described, no reference will be made to the internal occurrences during the repeated divisions by which the form of the animal is built up.

A fertilized egg-cell that contains little food-yolk divides first of all completely into two cells. Then each of these divides, forming four cells, each of these again forming eight, and each of the eight forming sixteen. The cells, or **segmentation spheres** or **blastomeres**, as they are called, assume a spherical form after each division, and, as they adhere closely to each other, the whole embryo, after the four-cell stage, is a round, solid mass of cells with only the little interspaces between the cells that are the necessary result of the rounded form of the individual cells. Recent investigations have shown that the blastomeres are not merely in contact but are connected with each other by fine strands of protoplasm. In some cases and perhaps in all, these fibrils become later differentiated into nerves.

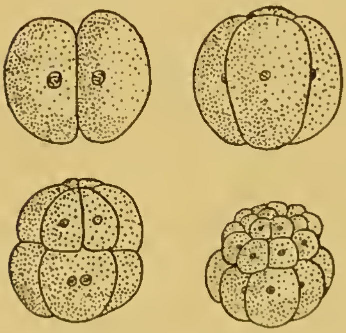

Fig. 67.—Four stages in cleavage; resulting in the Morula.

Sometimes there is more of the food-yolk present in some of the blastomeres than in the others. When this occurs it begins to be specially noticeable at the eight-cell stage. Four of these may be larger and contain most of the food material, the other four being smaller. The smaller cells are said to form the **animal pole**,[1] and from them the ectoderm of the animal is formed, while the larger, food-containing cells lie at what is called the **vegetative pole**, and give rise to the endoderm. On the other hand, no difference between the individual cells may be visible up to the sixteen-cell stage. Moreover, experiments show that there may be in some cases, at any rate, no difference between the characters and nature of the first sixteen cells. It has been found possible, by shaking embryos of the two-, four-, eight-, and sixteen-cell stages, completely to separate the cells from each other, and it has resulted that each of the separated cells, by division on its own account, formed an embryo by itself, the only difference being that these embryos were proportionately smaller. It should, however, be borne in mind that in a later stage of development this is not true. For then differentiation has occurred, and the experimental elimination from the developing embryo of specific blastomeres results in the absence of definite organs from the later embryo.

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[1] The animal pole is the pole at which the polar bodies were extruded.

The sixteen-cell stage from its appearance is called the **morula** or mulberry stage, and may be compared to a colonial protozoon. Its cells multiply rapidly by repeated division, and give rise to a single layered hollow sphere, the **blastosphere,** a section through which is represented in Fig. 68. In this stage, whether or no a distinction between the cells at the animal pole and the larger cells of the vegetative pole has previously appeared, such poles become obvious. The blastosphere, then, is a hollow sphere of cells arranged in a layer, one cell thick, with larger cells towards the lower or vegetative pole, and smaller cells towards the animal pole. The central cavity is termed the **segmentation cavity.** The next stage consists in the assumption of the **cœlenterate** or **two-layered** type. This takes place by the larger cells moving inwards to form the inner layer. The simplest method by which this occurs in the embryos of the vertebrate group is by the **invagination,** or infolding, of

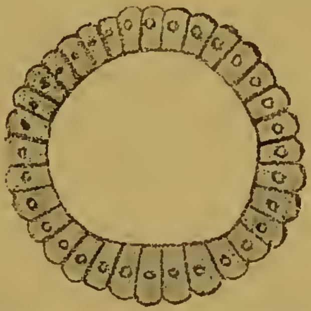


FIG. 68.—Section through Blastosphere.

the cells of the vegetative pole without any break in their continuity, as when a hollow indiarubber ball, pricked so that the air has escaped, shows a dimple that may be pushed in by the finger until the ball is turned into a two-layered cup. The embryo has now reached the cœlenterate type and is what is called a **gastrula** (Fig. 69). The central cavity is the **enteron,** the mouth of the gastrula is what is called the **blastopore.** The layers, in the embryonic condition, are given names which distinguish them from the similar layers of adult animals. The outer layer which corresponds to the ectoderm of *Hydra* is called the **epiblast.** The inner layer corresponding to the endoderm of *Hydra* is called the **hypoblast.** These two are the primitive germinal layers. The third layer which was spoken of as the mesoderm, and which is characteristic of the cœlomates, is termed the mesoblast, and, unlike the epiblast and hypoblast, is not a primary layer arising directly from the blastosphere. It is derived in different ways from the two primary layers, and consists of a reticulum of cells which later becomes very divergently differentiated.

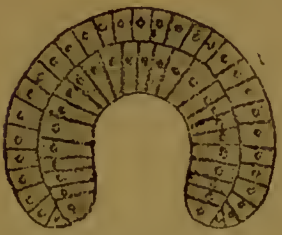


FIG. 69.—Section through early invaginate gastrula.

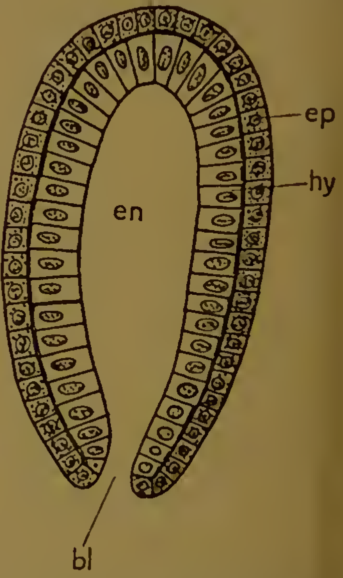


FIG. 70.—Section through a later Gastrula. **bl.** Blastopore. **en.** Enteron (archenteron). **ep.** Epiblast. **hy.** Hypoblast.

The subsequent development of the gastrula into the cœlomate type becomes more and more complicated, and one has to notice several processes separately which are going on simultaneously in the actual development. Moreover, the general assumption of the cœlomate type is accompanied by the appearance of structures which are different in different groups of the cœlomates. It is therefore necessary to follow one of the types of cœlomate structure. That chosen here is the Vertebrate or Chordate type.

First of all the gastrula becomes elongated (Fig. 70) and the blastopore lies at the posterior end. The opening becomes very much smaller on account of gradual growth round its edges. This growth is, however, not quite regular, but is more rapid at the sides and at the edge corresponding to the future ventral surface of the animal. Thus it happens that the blastopore gets pulled out into a long slit-like aperture, which extends a small distance over the dorsal surface of the embryo and terminates at the posterior end of the embryo.

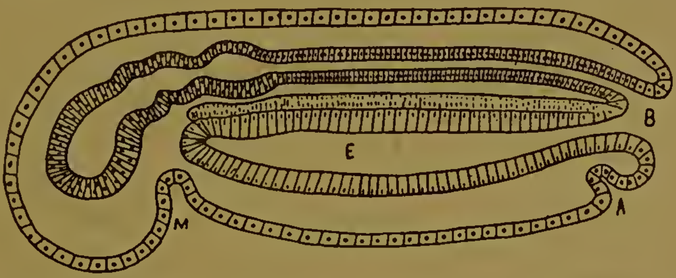


FIG. 71.—Longitudinal vertical section through a later stage. **B.** Blastopore leading into dorsally the nerve-tube, which in front is expanded into the three primitive vesicles of the brain; the blastopore lower down leads into **E**, the enteron, along the dorsal wall of which an expansion is forming the notochord. **M.** Invagination of epiblast to form the mouth; **A**, to form the **anus.**

Meantime a longitudinal furrow or groove appears along the dorsal surface of the epiblast from the anterior edge of the blastopore towards the anterior end. This groove becomes deeper and deeper, and finally its edges meet over the open groove and thus transform the groove into a canal (Fig. 74). This tube, arising from the epiblast along the dorsal line, forms the nervous system of Vertebrates. The tube sinks down and the epiblast closes over it. At the anterior end it becomes enlarged to form three primary vesicles of the brain. Its posterior part forms the spinal cord, and the cavity of the tube becomes the cavity of the brain in front and the central canal of the spinal cord behind. The primar vesicles alter as described on page 226. At first this can opens into the blastopore behind, but the lips of the elon gated blastopore close over and meet just as the edges of th nerve furrow grew together to form a tube. In this way th spinal canal passes round the posterior end of the embry under the closed lips of the blastopore and opens into th enteron or primitive gut. Thi connexion is called the **neurenteric** canal, because it passe from the neural canal to the enteron (Fig. 71). Shortly afterward a small pit appears in the epiblas just below the closed edge of th blastopore. This epiblastic pi grows deeper until it break through into the posterior en of the enteron. This new opening forms the anus of the animal. Upon its appearance the neurenteric canal is obliterated and the nervous tube becomes closed at the posterior end. At the anterior end of the body of the embryo on the ventral surface an epiblastic pit like that which formed the anus appears. This grows deeper, and breaks through into the anterior blind end of the enteron and forms the mouth and buccal cavity of the animal. At each side of the anterior end of the body, behind the mouth, four or five elongate, shallow epiblastic pits appear. These grow in towards the hypoblastic walls of the enteron, and opposite each epiblastic pit a hollow hypoblastic bud grows out. The latter reach nearly to the outside, and come into contact with the epiblastic pits; the opposed walls of the two sacs become absorbed, and in this way four or five slit-like apertures from the exterior open

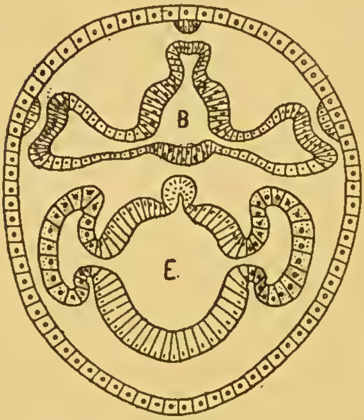


FIG. 72.—Transverse section through stage later than Fig. 71, taken through the thalamencephalon. **B.** Cavity of the ventricle with a dorsal prolongation forming the pineal, and lateral prolongations forming the lateral eyes. Opposite these a thickening in the epiblast is the rudiment of the lens. **E.** The enteron surrounded by hypoblast cells, with a dorsal fold—the notochord, and lateral folds—the enterocœles.

into the anterior sides of the enteron. These form the **gill-slits** (Fig. 73).

While these important changes have been going on in the epiblast an equally important set of changes results in the formation of the **cœlome.** The simplest method of this among the Vertebrates consists of the formation of a number of pairs of outgrowths from the enteron. These outgrowths or **enterocœles** are hollow buds from the hypoblast (Fig. 73), which arise opposite each other all along the length of the gut, beginning from the anterior end. At the same time all along the dorsal line of the enteron opposite and below the epiblastic nerve tube there is formed a fold of the hypoblastic wall of the gut. The lateral buds or enterocœles and the dorsal fold separate from the gut at the same time. The walls of the dorsal fold separate from the gut, grow together, and transform the fold into a long solid rod of cells lying between the nerve-tube and the gut. This rod of cells is the **notochord** or **chorda dorsalis,** and is the predecessor of the vertebral column. The enterocœlic pouches meet each other and their opposed walls are then absorbed, so that a continuous cavity along the sides of the gut is formed. They also meet the pouches of the opposite side underneath the surface of the gut. Thus there is formed a space, the **cœlome** of the future animal, folded round the gut and continuous under it, but not above it, as the notochord lies between the edges of its walls. A rough model of the arrangement of these structures will make their relations clearer. Suppose we represent the gut by a piece of drain-pipe. A solid cylindrical rod of wood like the piece of a mast may be fixed along the top of this to represent the notochord. Next let us take a flock mattress of the same length as the drain-pipe and place the drain-pipe with the rod of wood fixed along its upper surface on the middle of the mattress along its length. Then let the free parts of the mattress be bent round the drain-pipe until the two edges are in contact with each side of the rod of wood. The flock or stuffing of the mattress represents the hollow of the cœlome. The ticking of which the mattress is made represents the cellular walls of the cœlome. The upper surface of this is closely applied to the drain-pipe or gut where it is in contact with the notochord or rod of wood. The upper surface is continuous with the under, which, however, runs right round the pipe, separated from the outer surface by the stuffing or cœlomic cavity, until at the other side of the notochord it again meets the upper edge. In the actual embryo, however, the outer and inner layers are fused together for a short distance on each side of the notochord. These fused longitudinal bands lying on each side of the noto chord very early exhibit signs of segmentation, which is a striking character in the bodies of Vertebrates. They break up into a row of what are called primitive segments, and from these are formed among other things all the transversely striped voluntary muscles of the body. The remaining part of the wall of the cœlome remains in the adult as the lining epithelium of the body cavity.

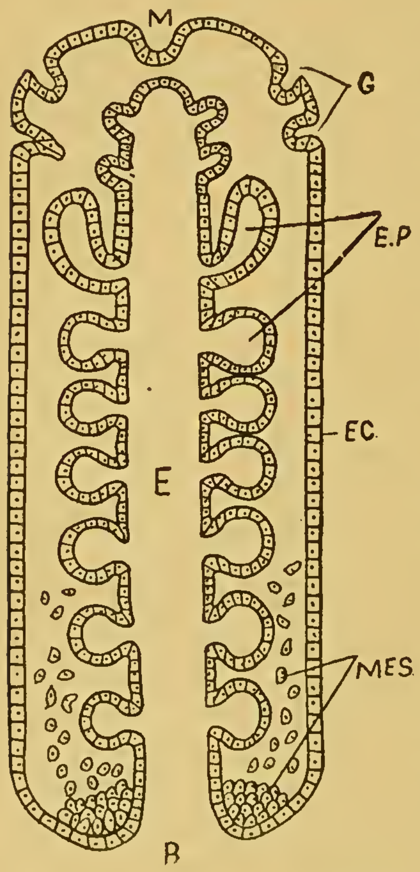


FIG. 73.—Horizontal longitudinal section through a simple Vertebrate Embryo in region of Enteron. **M.** Invagination of epiblast to form mouth. **G.** Invaginations of epiblast to form gill-slits. **B.** Blastopore. **E.** Enteron lined by hypoblast. The wall of the enteron in front has lateral diverticula which run towards the epiblastic gill invaginations. **EP.** Paired enterocœles, the cavities of which fuse to form the cœlome, and the walls of which form part of the mesoblast. **MES.** Mesenchyme cells migrating inwards from round walls of blastopore.

These structures formed from the walls of the enterocœlic pouches form a great part of the mesoblast or middle embryonic layer of vertebrates. But with it there come to be associated structures which have no direct connexion with the enterocœle. First of all the sexual cells, those which give rise to the ovary and to the testis, in some cases are separated from the developing ovum before even the blastosphere stage, and therefore before the epiblast and hypoblast become distinct. In other cases they do not become visible as separate cells till later. In the Vertebrates these primitive sexual cells, at whatever time they be actually separated from the other cells, become associated with the mesoblast, and appear as prominent patches of cells in the inner wall of the body cavity high up near the place where the outer and inner walls of the body cavity fuse together to form the primitive segments.

Next there is reason to believe that the nephridia, out of which the kidneys of Vertebrates are formed, are partly at least epiblastic organs, but in Vertebrates the first appearance of these as structures that can be identified is in the mesoblastic wall of the cœlome near the genital cells. So the beginning of these excretory organs is part of the mass of cells called the mesoblast.

Lastly, in some lower groups of cœlomates a set of wandering amœboid cells liberate themselves from both epiblast and hypoblast, and pass between the cœlome and the epiblast and hypoblast. These cells give rise to the blood corpuscles, to cœlomic corpuscles where, as in the earthworm, such exist, to the blood-vessels, and to the connective tissue and skeletal structures. In Vertebrates these wandering cells, which have been called the **mesenchyme,** appear to be derived chiefly but not entirely from the inner layer of hypoblast, but they are detached chiefly from the walls of the gastrula around the lips of the blastopore. But they are distinguished by the fact that they come off not as layers or pouches of cells, but as separate migratory cells which are budded off in definite places.

In the case of heavily yolk-laden eggs, like those of birds and reptiles, a typically gastrula stage is not passed through. But instead a flattened double layered membrane, called the **blastoderm** (Fig. 74), is formed, which is referable in its essential features to a gastrula type. It is as though the

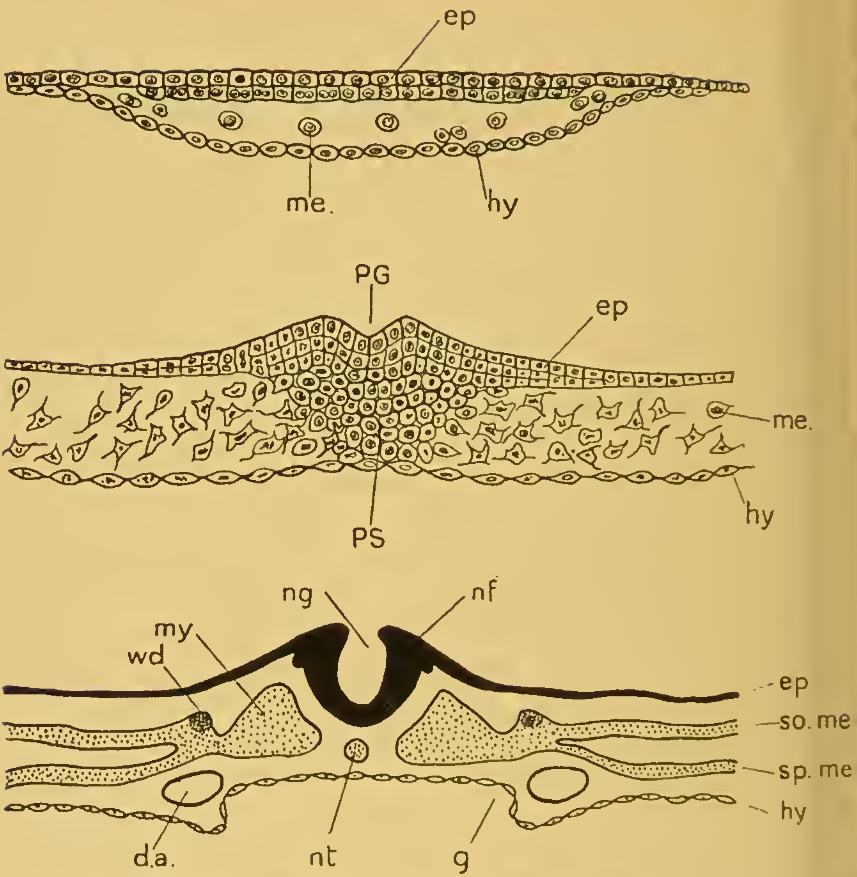


FIG. 74.—The top figure represents a transverse section of the blastoderm of the Chick. It shows the epiblast and hypoblast. The latter is confluent with the former along the margins of the blastoderm, and some of the lower layer cells, from which the hypoblast has arisen, remain in the space between the two first germinal layers, to give rise to the beginnings of the third germinal layer, or mesoblast.

The middle figure represents a transverse section through the primitive streak of the Chick's blastoderm. It shows the origin of the mesoblast from the proliferating epiblast of the streak. Along the length of the primitive streak the three germinal layers—epiblast, mesoblast, and hypoblast—are confluent. The streak is traversed by a primitive groove.

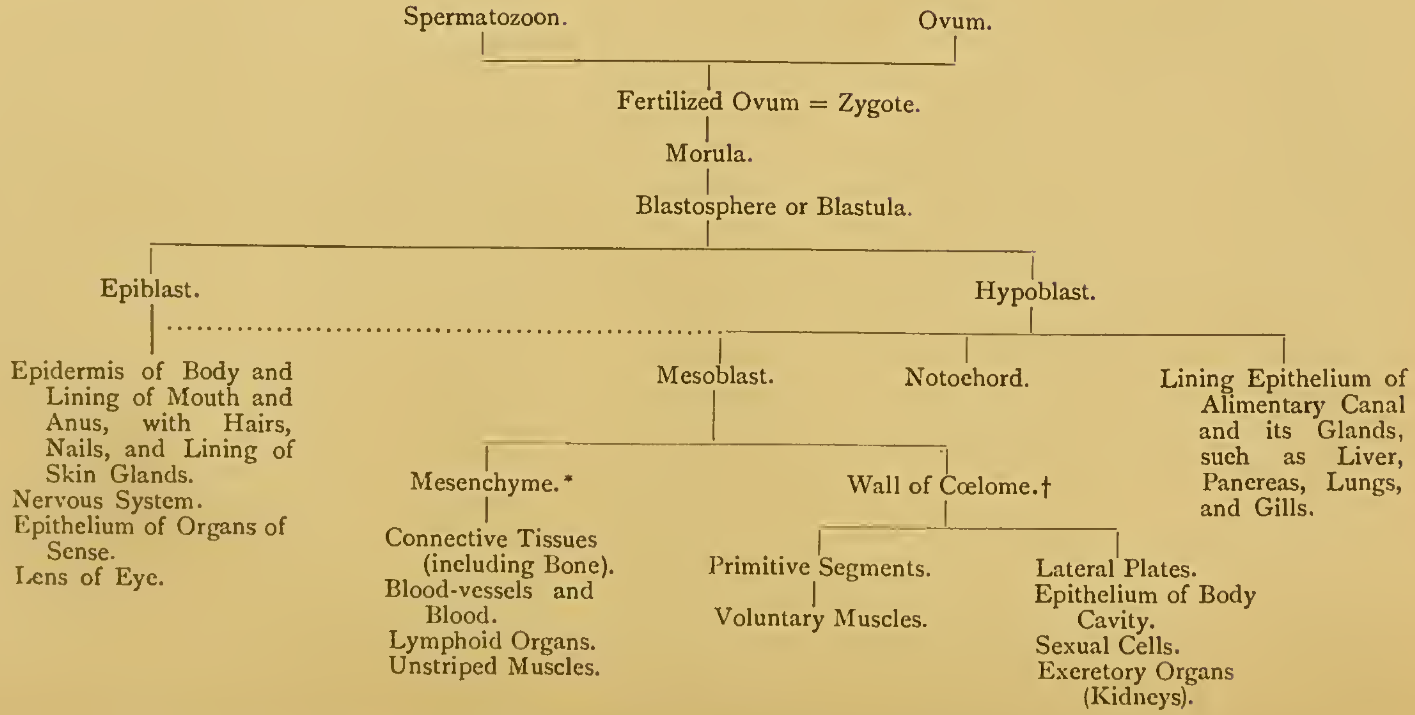
The lowest figure represents a transverse section through a second day blastoderm. It shows the origin of the cœlom by the separation ("splitting") of the primary single sheet of mesoblast into somatic and splanchnic layers. It also shows the origin of the central nervous system as a thickened epiblastic plate, which becomes folded upon itself along its longitudinal axis. The neural folds meet and fuse later on and form a closed tube, lying beneath the epiblast. The formation of the gut by a similar folding of the hypoblast is also shown. **d.a.** Dorsal aorta. **ep.** Epiblast. **g.** Canal of developing gut. **hy.** Hypoblast. **me.** Mesoblast. **my.** Myotome. **n.f.** Neural fold. **n.g.** Neural groove. **nt.** Notochord. **P.G.** Primitive groove. **P.S.** Primitive streak. **so.me.** Somatic layer of mesoblast. **sp.me.** Splanchnic layer of mesoblast. **w.d** Developing Wolffian duct.

epiblast (ep) and hypoblast (hy) of a gastrula had been flattened out and spread over the surface of the large egg. In a blastoderm such as this the mesoblast arises in three ways : (1) from some of the earlier cells of the segmentation before the hypoblast is definitely differentiated (me, upper figure). (2) From the edges of the hypoblast after its differentiation. (3) From a ridge of epiblast (PS) formed at the posterior end of the blastoderm ; from this mesoblast cells (me, middle figure) are proliferated off into the space between the hypoblast (hy) and epiblast (ep).

This epiblastic ridge becomes confluent with the adjacent hypoblast beneath, and since the proliferating mesoblast is budding off from it, it follows that at this point all three germinal layers are, as it were, fused together. Now in those developing gastrulæ, in which mesoblast develops from the edges of the blastopore, there is the same confluence of the three germinal layers. We may, for this reason and others, conclude that the epiblastic ridge, which is known as the **primitive streak** (PS), represents a closed blastopore.

It is clear, then, that the mesoblast or middle layer of Vertebrates is not a simple structure like the hypoblast and epiblast, but is a condensation of a great many separate elements.

From the three germinal layers all the tissues of the definitive organism are formed. We may put together in a tabular form the primitive organs of the embryo and the structures to which these give rise :—


Spermatozoon.
Ovum.
Fertilized Ovum = Zygote.
Morula.
Blastosphere or Blastula.
Epiblast.
Hypoblast.
Epidermis of Body and Lining of Mouth and Anus, with Hairs, Nails, and Lining of Skin Glands.
Nervous System.
Epithelium of Organs of Sense.
Lens of Eye.
Mesoblast.
Notochord.
Lining Epithelium of Alimentary Canal and its Glands, such as Liver, Pancreas, Lungs, and Gills.
Mesenchyme.*
Wall of Cœlome.†
Connective Tissues (including Bone).
Blood-vessels and Blood.
Lymphoid Organs.
Unstriped Muscles.
Primitive Segments.
Voluntary Muscles.
Lateral Plates.
Epithelium of Body Cavity.
Sexual Cells.
Excretory Organs (Kidneys).

* This is the reticular, non-epithelial portion of the mesoblast.

† This is the epithelial portion of the mesoblast.

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